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Using solar availability factors to adjust cool-wall energy savings for shading and reflection by neighboring buildings

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Abstract

The extent to which a solar-reflective "cool" wall can reduce a building's cooling load in summer or increase its heating load in winter scales with the wall's incident solar radiation, or solar availability. We assess how the solar availability at the wall of a central (modeled) building is affected by a neighboring wall across an urban canyon by calculating the central wall's solar availability factor (SAF), defined as the ratio of sunlight incident on the central wall in the presence of the neighboring wall to that incident in the absence of the neighboring wall. Cool-wall heating, ventilation, and air conditioning (HVAC) energy savings simulated for an isolated central building (no neighbors) can be multiplied by SAFs to account for interactions with neighboring walls.

Monthly values of SAF were evaluated in 17 climates across the United States, including three in California, for north, east, south, and west central walls, over a wide range of canyon aspect ratio (height/width). Results for four representative aspect ratios—0.2, 1, 2, and 10—are presented. In Fresno, CA, monthly SAF ranges from 0.90 to 0.96 for central walls facing north, east, south, or west when the aspect ratio is 0.2 (two-story single-family homes across a street) and both the central and neighboring walls are conventional (albedo 0.25). Monthly SAFs decrease as aspect ratio rises, falling to 0.06 – 0.24 at an aspect ratio of 10 (adjacent 10-story buildings on the same side of the street).

An example worked for a two-story single-family home in Fresno on the west side of a residential street yields SAFs of 0.47 (north), 0.92 (east), 0.50 (south), and 0.63 (west) to apply to the cool-wall annual HVAC energy savings computed for an isolated central building. Shading and reflection reduce the home's annual HVAC energy cost savings by 31%.

Keywords

Solar availability factor; cool walls; shading; reflection; cooling energy savings; heating energy penalty

Nomenclature

English symbols

a	Reflection multiplier
b	Reflection multiplier
c	Reflection multiplier
f	Solar availability factor
F	View factor
g	Fractional increase in solar irradiation
H	Building height
I	Solar irradiance
J	Ground shadow length
L	Canyon depth
Q	Solar power
Q''	Solar power per unit left wall area
R	Canyon aspect ratio (height/width)
t	Time
W	Ground (canyon floor) width

Greek symbols

γ	Wall surface-solar azimuth angle
θ	Solar beam incidence angle
θ_z	Solar zenith angle
ρ	Albedo (solar reflectance)
ϕ	Solar azimuth angle
ψ	Wall azimuth angle

Abbreviations

BH	Beam horizontal
BN	Beam normal
C	Ceiling
DH	Diffuse horizontal
ESM	Electronic supplementary material
G	Ground
HVAC	Heating, ventilation, and air conditioning

i	Incident
LW	Left wall
RW	Right wall
SAF	Solar availability factor
SFW	Sun-facing wall

1 Introduction

The extent to which a solar-reflective "cool" wall can reduce a building's cooling load in summer or increase its heating load in winter scales with the wall's incident solar radiation, or solar availability. The solar availability at the wall of a central (modeled) building can be lowered by shadows cast by neighboring buildings and raised by sunlight reflected from neighboring buildings. The influence of interbuilding shading and reflection on solar availability has been explored with two-dimensional models (Nunez & Oke 1980; Arnfield 1990; Kusaka et al. 2001; Fortuniak 2008). Three-dimensional tools, such as Ecotect Analysis (Autodesk 2018), Heliodon2 (Beckers 2018), and ArcGIS (ESRI 2018) have been used to assess the effect of shading alone (Andreou 2014; Garcia-Nevado et al. 2016; Jaugsch & Löwner 2016) or of both shading and reflection (Catita et al. 2014). Other studies have modeled tree shading of building walls (Simpson & McPherson 1998; Brown 1998; Andreou 2014) or roofs (Levinson et al. 2009).

Hourly building energy modeling tools such as eQUEST (JJH 2018) and EnergyPlus (USDOE 2018) can implement interbuilding shading and reflection (e.g., Ichinose et al. 2017). However, this adds many computationally intensive simulations. For example, modeling neighbors at four different distances from the four walls of a central building would add 16 simulations per prototype. Therefore, Rosado & Levinson (2018) used EnergyPlus to simulate cool-wall energy savings without considering shading or reflection by neighboring structures or trees.

The current study evaluates the solar availability factor (SAF) of a wall of a central building ("central wall"), defined as the ratio of sunlight incident on the central wall in the presence of the neighboring wall to that incident in the absence of the neighboring wall. Since past studies of cool roof energy savings have found that cooling savings and heating penalties are linearly proportional to rise in roof solar reflectance, or "albedo" (Konopacki et al. 1997; Gao et al. 2014), we propose to scale the heating, ventilation, and air conditioning (HVAC) savings simulated for each cool wall of an isolated (neighborless) central building by its solar availability factor to account for interactions with the neighboring wall. We can also use SAF to assess the effect of raising neighboring wall albedo on the solar availability of the central wall. Each daily or monthly SAF is specific to a particular wall orientation and geographic location.

Our analysis emphasizes simplicity so that its results can be applied knowing only wall orientation, canyon aspect ratio (ratio of building height to building separation), city, and month.

It does not consider shading or reflection by surfaces other than neighboring walls, such as trees, and assumes that each wall exhibits uniform and Lambertian (perfectly diffuse) reflectance.

The study develops the theory required to calculate solar availability from urban canyon geometry and readily available solar irradiance data, computes these factors for four urban canyon geometries in 17 U.S climates, and provides an example of their application to cool-wall savings simulated for an isolated single-family home in Fresno, CA.

2 Theory

The wall irradiance model developed here is similar to that of Kusaka et al. (2001).

2.1 Geometry

Consider a two-dimensional canyon formed by a pair of adjacent buildings of equal height and infinite extent (Figure 1). Let H = building height, W = ground (canyon floor) width, L = canyon depth, and J = ground shadow length, each dimensional. Let θ_z = solar zenith angle and ϕ = solar azimuth angle. Azimuth angles are measured clockwise from north such that 0° is north and 90° is east.

Let subscripts LW, RW, SFW, G, and C designate the canyon's left wall, right wall, sun-facing wall, ground, and ceiling, respectively. Let ψ represent wall azimuth angle and let wall surface-solar azimuth angle $\gamma = \phi - \psi$. When the solar beam is normal to the wall, γ = 0 and $\cos\gamma$ = 1; when the solar beam is parallel to the wall, γ = ±90° and $\cos\gamma$ = 0; and when the solar beam is behind the wall, γ < -90° or γ > 90°, and $\cos\gamma$ < 0.

Let I_{BH} = beam (direct) horizontal irradiance; I_{DH} = diffuse horizontal irradiance; ρ = albedo (solar reflectance); $R \equiv H/W$ = canyon aspect ratio; and ground shadow length (normal to wall)

$$J = \min(H \times \tan\theta_z \times \cos\gamma_{\mathrm{SFW}}, W). \quad (1)$$

It follows from Eq. (1) that the shadow will not cross the canyon when $\tan\theta_z \times \cos\gamma_{\mathrm{SFW}} < 1/R$, and that the sun-facing wall will be unshaded when the solar zenith angle

$$\theta_z < \mathrm{atan}\,[1/(R \times \cos\gamma_{\mathrm{SFW}})]. \quad (2)$$

Since $0 < \cos\gamma_{\mathrm{SFW}} \leq 1$, the sun-facing wall will also be unshaded during the subset of these times when

$$\theta_z < \mathrm{atan}\,(1/R). \quad (3)$$

We show in Appendix A that the cumulative irradiance (solar power per unit area) striking the left wall after no more than two reflections from canyon surfaces will be

$$I_{\mathrm{LW}} = a \times Q''_{\mathrm{i,LW}} + b \times Q''_{\mathrm{i,RW}} + c \times Q''_{\mathrm{i,G}}, \quad (4)$$

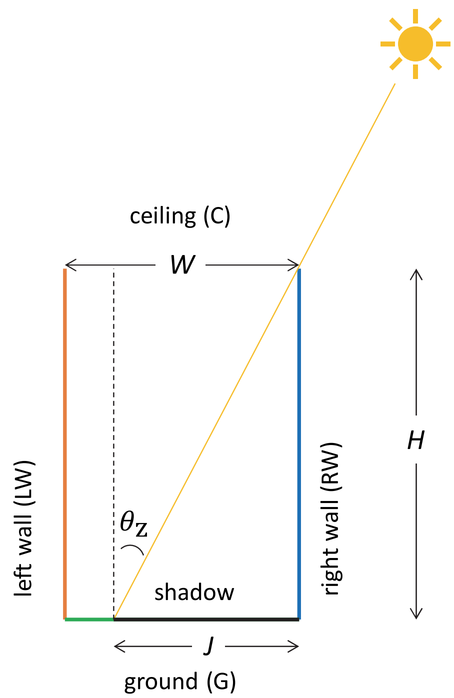


Figure 1. Canyon of width W formed by walls of adjacent buildings of equal height H and infinite extent into page. Ground shadow length is J and solar zenith angle is θ_z.

where

$$a = 1 + \rho_{\mathrm{LW}} \times (F_{\mathrm{LW}\to\mathrm{G}} \times \rho_{\mathrm{G}} \times F_{\mathrm{G}\to\mathrm{LW}} + F_{\mathrm{LW}\to\mathrm{RW}} \times \rho_{\mathrm{RW}} \times F_{\mathrm{RW}\to\mathrm{LW}}) \tag{5}$$

$$b = \rho_{\mathrm{RW}} \times (F_{\mathrm{RW}\to\mathrm{LW}} + F_{\mathrm{RW}\to\mathrm{G}} \times \rho_{\mathrm{G}} \times F_{\mathrm{G}\to\mathrm{LW}}) \tag{6}$$

$$c = \rho_{\mathrm{G}} \times (F_{\mathrm{G}\to\mathrm{LW}} + F_{\mathrm{G}\to\mathrm{RW}} \times \rho_{\mathrm{RW}} \times F_{\mathrm{RW}\to\mathrm{LW}}) \tag{7}$$

are reflection multipliers and

$$Q''_{\mathrm{i,LW}} = [I_{\mathrm{BH}} \times (J/H) + I_{\mathrm{DH}} \times F_{\mathrm{C}\to\mathrm{LW}}/R] \text{ if } \cos\gamma_{\mathrm{LW}} > 0, \text{ or } (I_{\mathrm{DH}} \times F_{\mathrm{C}\to\mathrm{LW}}/R) \text{ otherwise} \tag{8}$$

$$Q''_{\mathrm{i,RW}} = [I_{\mathrm{BH}} \times (J/H) + I_{\mathrm{DH}} \times F_{\mathrm{C}\to\mathrm{RW}}/R] \text{ if } \cos\gamma_{\mathrm{RW}} > 0, \text{ or } (I_{\mathrm{DH}} \times F_{\mathrm{C}\to\mathrm{RW}}/R) \text{ otherwise} \tag{9}$$

$$Q''_{\mathrm{i,G}} = I_{\mathrm{BH}} \times [(1/R) - (J/H)] + (I_{\mathrm{DH}} \times F_{\mathrm{C}\to\mathrm{G}})/R \tag{10}$$

are the initial radiative powers per unit left wall area incident on the left wall, right wall, and ground, respectively. View factors

$$F_{\mathrm{C}\to\mathrm{G}} = \sqrt{1+R^2} - R, \tag{11}$$

$$F_{\mathrm{C}\to\mathrm{LW}} = F_{\mathrm{C}\to\mathrm{RW}} = (1 - F_{\mathrm{C}\to\mathrm{G}})/2, \tag{12}$$

$$F_{\mathrm{G\to LW}} = F_{\mathrm{G\to RW}} = F_{\mathrm{C\to LW}}, \tag{13}$$

$$F_{\mathrm{LW\to G}} = F_{\mathrm{G\to LW}}/R, \tag{14}$$

$$F_{\mathrm{RW\to G}} = F_{\mathrm{G\to RW}}/R, \tag{15}$$

and

$$F_{\mathrm{LW\to RW}} = F_{\mathrm{RW\to LW}} = 1 - (2/R) \times F_{\mathrm{C\to LW}}. \tag{16}$$

2.2 Isolated-wall irradiance

Following the standard isotropic sky model (Duffie and Beckman 2006), the global irradiance on an isolated wall is

$$I_{\mathrm{W,isolated}} = I_{\mathrm{BN}} \times \cos\theta + \frac{I_{\mathrm{DH}} + (I_{\mathrm{BH}} + I_{\mathrm{DH}})\rho_{\mathrm{G}}}{2} \text{ if } \cos\theta > 0, \quad \text{or } \frac{I_{\mathrm{DH}} + (I_{\mathrm{BH}} + I_{\mathrm{DH}})\rho_{\mathrm{G}}}{2} \text{ otherwise;} \tag{17}$$

where beam-normal solar irradiance

$$I_{\mathrm{BN}} = I_{\mathrm{BH}} / \cos\theta_{\mathrm{z}}; \tag{18}$$

and the solar beam's incidence angle θ is given by

$$\cos\theta = \sin\theta_{\mathrm{z}} \cos\gamma. \tag{19}$$

Combining,

$$I_{\mathrm{W,isolated}} = I_{\mathrm{BN}} \times \tan\theta_{\mathrm{z}} \times \cos\gamma + \frac{I_{\mathrm{DH}} + (I_{\mathrm{BH}} + I_{\mathrm{DH}})\,\rho_{\mathrm{G}}}{2} \text{ if } \cos\theta > 0, \quad \text{or } \frac{I_{\mathrm{DH}} + (I_{\mathrm{BH}} + I_{\mathrm{DH}})\rho_{\mathrm{G}}}{2} \text{ otherwise.} \tag{20}$$

We can compare this to the left-wall irradiance predicted by our canyon model, I_{LW}, when $W \to \infty$ and the sun is above the horizon (keeping $\tan\theta_{\mathrm{z}}$ finite and less than $1/R$). If the left wall faces the sun,

$$\lim_{R\to 0} I_{\mathrm{LW}} = I_{\mathrm{BH}} \times \tan\theta_{\mathrm{z}} \times \cos\gamma_{\mathrm{LW}} + \frac{I_{\mathrm{DH}} + (I_{\mathrm{BH}} + I_{\mathrm{DH}})\,\rho_{\mathrm{G}}}{2}, \tag{21}$$

while if it opposes the sun,

$$\lim_{R\to 0} I_{\mathrm{LW}} = \frac{I_{\mathrm{DH}} + (I_{\mathrm{BH}} + I_{\mathrm{DH}})\,\rho_{\mathrm{G}}}{2}. \tag{22}$$

Each limiting result agrees with the corresponding isolated-wall irradiance predicted by the isotropic sky model.

2.3 Solar availability factor

We can now calculate the left wall's hourly solar availability factor (SAF)

$$f \equiv I_{\mathrm{LW}}/I_{\mathrm{W,isolated}} \tag{23}$$

or its daily SAF

$$f_{\mathrm{daily}} \equiv \frac{\int_{\mathrm{day}} dt\, I_{\mathrm{LW}}}{\int_{\mathrm{day}} dt\, I_{\mathrm{W,isolated}}}\ , \tag{24}$$

where t is time, and the left wall and isolated wall face the same direction.

We can compute monthly SAF from monthly mean values of left-wall and isolated wall daily irradiation:

$$f_{\mathrm{monthly}} \equiv \frac{\text{mean daily left-wall irradiation}}{\text{mean daily isolated-wall irradiation}}. \tag{25}$$

2.4 Applications of solar availability factor

We orient the canyon (i.e., set ψ_{LW}) to place the central building at left and the neighboring building at right, making the left wall of the canyon the central wall and the right wall of the canyon the neighboring wall.

If f_{monthly} is roughly constant over the course of the year, we can scale both the cooling savings and heating penalties simulated for a wall of an isolated building by a single value of f_{monthly}. If there is substantial variation in f_{monthly}, we will need to consider its values in both the heating and cooling seasons.

We can also use SAF to assess the effect of raising neighboring wall albedo on the sunlight incident on the central building wall. For example, the fractional increase in monthly sunlight incident on the central building wall is

$$g_{\mathrm{monthly}} \equiv \frac{\text{mean daily left-wall irradiation, high-albedo neighbor}}{\text{mean daily left-wall irradiation, low-albedo neighbor}} - 1 = \frac{f_{\text{monthly, high-albedo neighbor}}}{f_{\text{monthly, low-albedo neighbor}}} - 1. \tag{26}$$

3 Methodology

Hourly and monthly SAFs were evaluated for 17 locations across the United States, including three in California: Burbank, Fresno, and San Francisco (Figure 2). Hourly values of diffuse horizontal irradiance I_{DH} and beam horizontal irradiance I_{BH} (calculated as global horizontal irradiance – diffuse horizontal irradiance) were obtained from the Typical Meteorological Year 3 (TMY3) weather file (NREL 2018b) representing each location (Table 1).

Mid-hour values of solar position were computed with the Measurement and Information Data Center Solar Position and Intensity (MIDC SOLPOS) Calculator provided by the National Renewable Energy Laboratory (NREL 2018a). Solar positions were evaluated in year 2015 to avoid leap days and leap seconds.

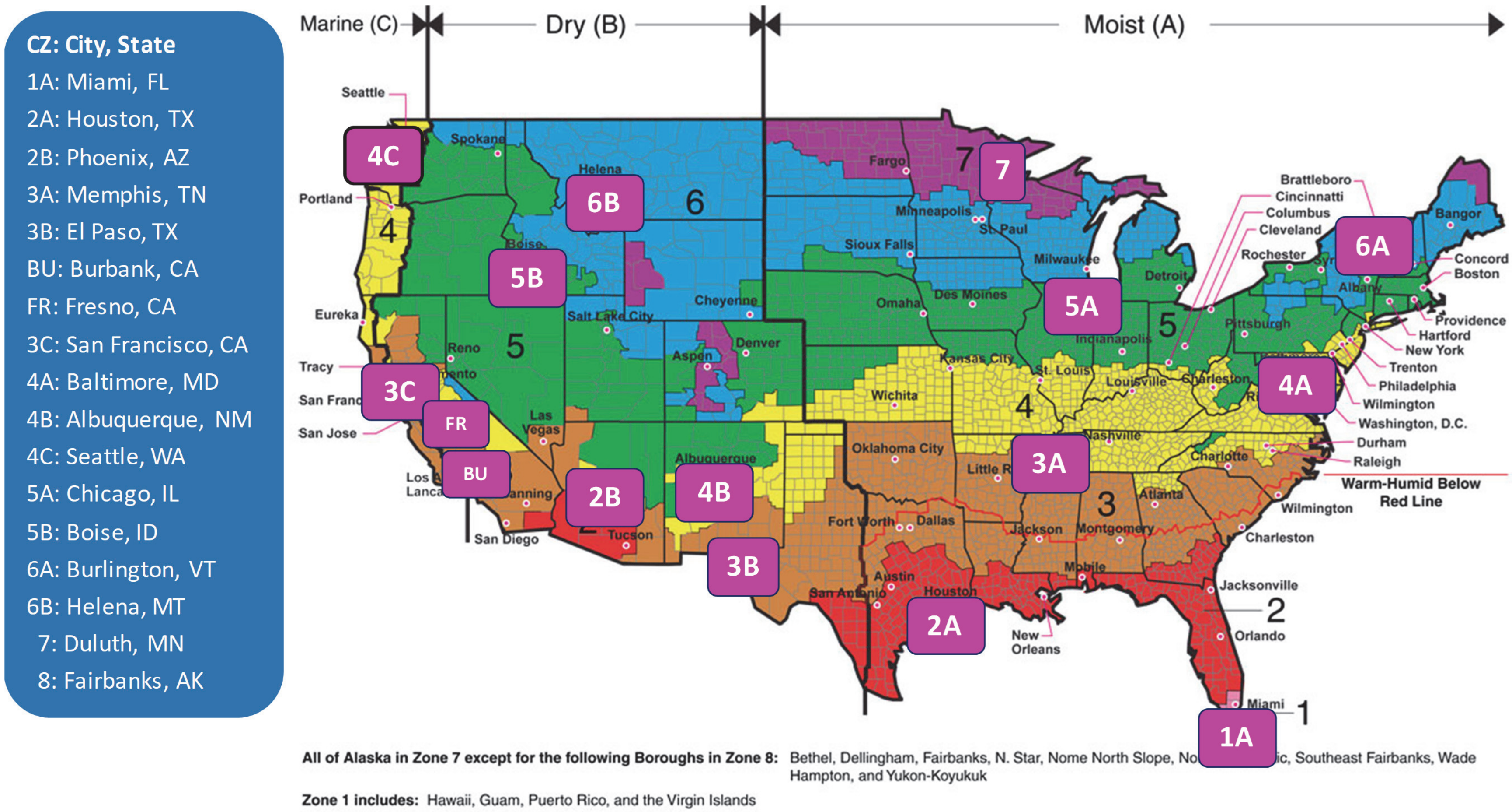


Figure 2. Map of U.S. climates in which solar availability factors were calculated. Climate zone 8 (Fairbanks, AK) is not shown. Source: Rosado and Levinson (2018).

Table 1. Location, site name, and site code of the Typical Meteorological Year 3 (TMY3) weather file used to characterize each climate.

Climate	City, State	USAF [a]	Site Name	Latitude (°N)	Longitude (°W)
1A	Miami, FL	722020	MIAMI INTL AP	25.82	80.30
2A	Houston, TX	722430	HOUSTON BUSH INTERCONTINENTAL	30.00	95.37
2B	Phoenix, AZ	722780	PHOENIX SKY HARBOR INTL AP	33.45	111.98
3A	Memphis, TN	723340	MEMPHIS INTERNATIONAL AP	35.07	89.98
3B	El Paso, TX	722700	EL PASO INTERNATIONAL AP [UT]	31.77	106.50
FR	Fresno, CA	723890	FRESNO YOSEMITE INTL AP	36.78	119.72
BU	Burbank, CA	722880	BURBANK-GLENDALE-PASSADENA AP	34.20	118.35
3C	San Francisco, CA	724940	SAN FRANCISCO INTL AP	37.62	122.40
4A	Baltimore, MD	724060	BALTIMORE BLT-WASHNGTN INT'L	39.17	76.68
4B	Albuquerque, NM	723650	ALBUQUERQUE INTL ARPT [ISIS]	35.04	106.62
4C	Seattle, WA	727930	SEATTLE SEATTLE-TACOMA INTL A	47.47	122.32
5A	Chicago, IL	725300	CHICAGO OHARE INTL AP	41.98	87.92
5B	Boise, ID	726810	BOISE AIR TERMINAL [UO]	43.62	116.21
6A	Burlington, VT	726170	BURLINGTON INTERNATIONAL AP	44.47	73.15
6B	Helena, MT	727720	HELENA REGIONAL AIRPORT	46.60	111.97
7	Duluth, MN	727450	DULUTH INTERNATIONAL ARPT	46.83	92.22
8	Fairbanks, AK	702610	FAIRBANKS INTL ARPT	64.82	147.85

[a] United States Air Force (USAF) code identifying TMY3 weather file.

SAFs were computed for central building walls facing north, east, south, and west in canyons with 29 aspect ratios ranging from 0 (infinitely wide canyon) to 90 (extremely narrow canyon). For simplicity, we focus on the results for four aspect ratios:

- R=0.2, representing two-story single-family homes across a residential street (H=6 m, W=30 m);
- R=1, representing two-story single-family across small back yards (H=6 m, W=6 m);
- R=2, representing adjacent two-story single-family homes on the same side of a street (H=6 m, W=3 m); and
- R=10, representing adjacent 10-story office buildings on the same side of the street (H=30 m, W=3 m).

Canyons with these four aspect ratios are drawn to scale in Figure 3.

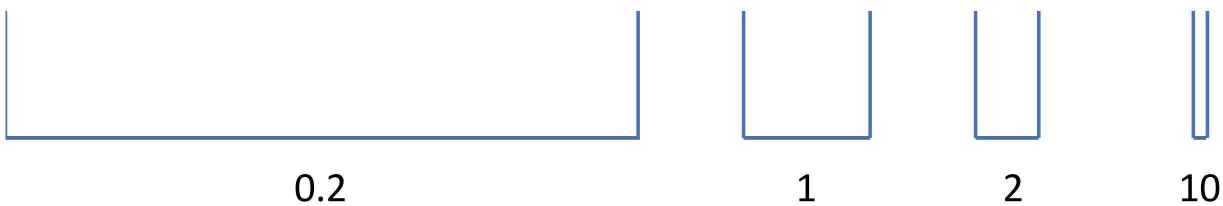


Figure 3. Canyon aspect ratio $R = H/W$ = 0.2, 1, 2, or 10.

SAFs were computed in four scenarios:

(1) conventional central wall with conventional neighboring wall;

(2) conventional central wall with cool neighboring wall;

(3) cool central wall with conventional neighboring wall; and

(4) cool central wall with cool neighboring wall.

Conventional and cool walls were assigned albedos 0.25 (dark-to-medium color) and 0.60 (off-white color), respectively. Ground albedo was fixed at 0.20, representing a lawn or aged pavement.

Scenario 3 is needed for comparison to scenario 1 and scenario 4 is needed for comparison to scenario 2 because (a) SAF depends on the albedo of the central wall [see Eq. (5)] and (b) the central wall's albedo rises when it is made cool. Close agreement between SAFs calculated in scenarios 1 and 3 and between SAFs computed in scenarios 2 and 4 would indicate that this dependency can be neglected.

Fractional increases in monthly central-wall irradiance upon raising neighboring-wall albedo were computed from monthly SAFs following Eq. (26).

4 Results and discussion

4.1 Monthly SAF statistics across United States

Table 2 reports for all 17 climates the annual mean, minimum, maximum, and range (maximum – minimum) values of monthly SAF in scenario 1 (conventional central wall with conventional neighboring wall) by climate, central wall orientation, and aspect ratio. Value for scenario 1 are also plotted versus latitude and aspect ratio in Figure 4, while corresponding values for the three remaining scenarios are presented in Electronic Supplementary Material (ESM)ESM Table B-1 to ESM Table B-3, and ESM Figure C-1 to ESM Figure C-3, of ESM Appendix B.

Within the mainland U.S.—i.e., latitudes 25°N to 50°N, which excludes climate zone 8 (Fairbanks, AK, near 65°N)—SAF at a given aspect ratio varies weakly with latitude (Figure 4) and climate zone subtype (Figure 5); the annual mean value of monthly SAF—hereafter, "annual mean SAF"—is nearly constant (bottom row of each panel in Table 2). However, there are modest to large seasonal variations in SAF driven by both shadow length and the fraction of incident sunlight that can be removed by a shadow—that is, the fraction of isolated-wall global solar radiation (energy/area) that is beam radiation. Table 3 reports by climate and season the beam fraction of global solar radiation incident on north, east, south, and west isolated walls, while Figure 6 plots its variation with latitude. Observe that the beam fraction of irradiation on an isolated south wall is much greater in winter than in summer (Figure 6c), magnifying the seasonal variation in south-wall SAF. In other words, in winter a south wall is exposed to long shadows, and a shadow on that wall can remove a large fraction of its global irradiance; in summer, the south wall is less shaded, and a shadow reaching that wall would remove a smaller fraction of its global irradiance.

To understand the interesting asymmetry between north-wall beam fractions in spring and fall (Figure 6a), note that the beam fractions are evaluated over the winter, spring, summer, and fall seasons, rather than on the winter solstice, spring equinox, summer solstice, and fall equinox. As defined here, spring (Mar-Apr-May) ends only three weeks before the summer solstice, while fall (Sep-Oct-Nov) begins more than 10 weeks after the summer solstice.

SAF in summer (the cooling season) is typically higher than annual mean SAF, while SAF in winter (the heating season) is typically lower than annual mean SAF. Therefore, if a building is cooled in summer and heated (or at least not cooled) in winter, multiplying an annual isolated-wall savings metric that encompasses both heating and cooling—e.g., annual HVAC energy cost savings—by the local annual mean SAF should yield a conservative (lower bound) estimate of the annual savings that will accrue to the central wall.

It is best to obtain the climate-specific values of annual mean SAF from Table 2 (scenario 1) or ESM Table B-1 to ESM Table B-3 (scenarios 2 – 4) of ESM Appendix B. However, since annual mean SAF varies only modestly across the mainland U.S. (Figure 4), one can approximate annual mean SAF in any of the mainland U.S. climates simulated here by the mainland-U.S. average for that scenario and orientation (Table 4).

Table 4 also shows close agreement between SAFs calculated in scenarios 1 and 3 and between SAFs computed in scenarios 2 and 4, with differences [(scenario 3 – scenario 1) and (scenario 4 – scenario 2)] in annual mean, minimum, and maximum SAF not exceeding 0.02. This indicates that SAFs calculated in scenarios 1 and 2 may be used to scale isolated-building cool wall savings without concern for the SAF rise induced by increasing central-wall albedo.

Table 2. Annual mean, minimum, maximum, and range (maximum – minimum) values of monthly SAF for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) with a conventional neighboring wall (ρ=0.25). Results shown by climate for aspect ratio of (a) R=0.2, (b) R=1, (c) R=2, or (d) R=10.

(a) Aspect ratio R=0.2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.91	0.91	0.92	0.02	0.92	0.89	0.94	0.05	0.93	0.91	0.96	0.05	0.91	0.84	0.94	0.10
2A (Houston, TX)	0.91	0.89	0.92	0.03	0.91	0.86	0.94	0.07	0.93	0.91	0.95	0.04	0.91	0.86	0.93	0.07
2B (Phoenix, AZ)	0.92	0.86	0.95	0.09	0.91	0.87	0.95	0.08	0.95	0.93	0.97	0.04	0.92	0.88	0.95	0.06
3A (Memphis, TN)	0.92	0.90	0.93	0.03	0.92	0.85	0.94	0.08	0.94	0.92	0.96	0.04	0.91	0.84	0.94	0.10
3B (El Paso, TX)	0.93	0.91	0.95	0.04	0.94	0.88	0.96	0.07	0.95	0.93	0.97	0.04	0.93	0.90	0.94	0.04
BU (Burbank, CA)	0.92	0.91	0.94	0.03	0.93	0.89	0.94	0.06	0.95	0.93	0.96	0.04	0.93	0.90	0.95	0.05
FR (Fresno, CA)	0.92	0.90	0.93	0.03	0.92	0.90	0.95	0.04	0.95	0.94	0.96	0.03	0.93	0.91	0.95	0.04
3C (San Francisco, CA)	0.91	0.88	0.94	0.06	0.92	0.87	0.94	0.07	0.95	0.93	0.96	0.03	0.92	0.89	0.94	0.05
4A (Baltimore, MD)	0.91	0.88	0.93	0.06	0.90	0.74	0.94	0.19	0.94	0.91	0.96	0.05	0.90	0.83	0.93	0.10
4B (Albuquerque, NM)	0.93	0.88	0.97	0.09	0.92	0.87	0.95	0.08	0.95	0.93	0.97	0.03	0.92	0.89	0.95	0.06
4C (Seattle, WA)	0.91	0.90	0.92	0.03	0.91	0.85	0.94	0.08	0.94	0.91	0.96	0.05	0.90	0.82	0.93	0.12
5A (Chicago, IL)	0.91	0.91	0.93	0.02	0.91	0.86	0.94	0.08	0.94	0.92	0.95	0.03	0.91	0.84	0.94	0.10
5B (Boise, ID)	0.92	0.90	0.94	0.03	0.91	0.86	0.94	0.08	0.95	0.92	0.96	0.04	0.91	0.86	0.95	0.09
6A (Burlington, VT)	0.91	0.87	0.93	0.06	0.90	0.82	0.93	0.11	0.94	0.90	0.95	0.05	0.90	0.85	0.93	0.08
6B (Helena, MT)	0.92	0.88	0.94	0.06	0.91	0.86	0.94	0.08	0.95	0.91	0.96	0.05	0.90	0.80	0.95	0.15
7 (Duluth, MN)	0.91	0.86	0.93	0.07	0.90	0.83	0.94	0.11	0.94	0.91	0.96	0.05	0.90	0.84	0.94	0.10
8 (Fairbanks, AK)	0.88	0.77	0.94	0.16	0.77	0.56	0.92	0.36	0.79	0.24	0.96	0.72	0.91	0.70	0.94	0.24
U.S. (excluding CZ 8)	**0.92**	**0.86**	**0.97**	**0.11**	**0.91**	**0.74**	**0.96**	**0.21**	**0.94**	**0.90**	**0.97**	**0.07**	**0.91**	**0.80**	**0.95**	**0.15**

Table 2 (continued)

(b) Aspect ratio R=1

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.65	0.62	0.69	0.08	0.63	0.59	0.66	0.07	0.70	0.61	0.80	0.19	0.63	0.57	0.66	0.09
2A (Houston, TX)	0.65	0.61	0.69	0.07	0.62	0.57	0.66	0.09	0.70	0.59	0.80	0.21	0.62	0.57	0.66	0.09
2B (Phoenix, AZ)	0.68	0.61	0.75	0.14	0.61	0.56	0.65	0.09	0.72	0.54	0.83	0.30	0.62	0.57	0.67	0.10
3A (Memphis, TN)	0.66	0.63	0.69	0.06	0.62	0.56	0.67	0.10	0.69	0.50	0.80	0.29	0.61	0.55	0.67	0.12
3B (El Paso, TX)	0.69	0.65	0.75	0.10	0.64	0.60	0.69	0.09	0.73	0.57	0.82	0.26	0.63	0.58	0.69	0.11
BU (Burbank, CA)	0.68	0.64	0.72	0.08	0.63	0.59	0.68	0.10	0.71	0.53	0.82	0.29	0.64	0.58	0.69	0.11
FR (Fresno, CA)	0.66	0.63	0.71	0.07	0.63	0.58	0.67	0.09	0.71	0.51	0.84	0.33	0.63	0.60	0.67	0.07
3C (San Francisco, CA)	0.66	0.62	0.69	0.07	0.63	0.56	0.68	0.12	0.70	0.47	0.83	0.36	0.63	0.58	0.66	0.09
4A (Baltimore, MD)	0.65	0.61	0.69	0.08	0.60	0.47	0.65	0.19	0.67	0.44	0.81	0.36	0.60	0.54	0.65	0.12
4B (Albuquerque, NM)	0.70	0.62	0.77	0.15	0.61	0.55	0.67	0.11	0.71	0.51	0.83	0.32	0.62	0.56	0.69	0.13
4C (Seattle, WA)	0.64	0.62	0.67	0.05	0.60	0.55	0.65	0.11	0.64	0.37	0.80	0.42	0.59	0.51	0.65	0.14
5A (Chicago, IL)	0.64	0.63	0.67	0.04	0.60	0.53	0.64	0.12	0.65	0.42	0.80	0.38	0.61	0.53	0.65	0.12
5B (Boise, ID)	0.67	0.64	0.72	0.08	0.59	0.51	0.65	0.13	0.68	0.39	0.85	0.46	0.60	0.53	0.66	0.14
6A (Burlington, VT)	0.63	0.59	0.66	0.07	0.59	0.52	0.64	0.12	0.65	0.39	0.78	0.40	0.59	0.53	0.64	0.11
6B (Helena, MT)	0.66	0.63	0.70	0.06	0.59	0.51	0.64	0.14	0.64	0.34	0.82	0.48	0.58	0.47	0.65	0.18
7 (Duluth, MN)	0.64	0.59	0.67	0.08	0.58	0.50	0.64	0.13	0.63	0.35	0.80	0.45	0.58	0.52	0.63	0.12
8 (Fairbanks, AK)	0.60	0.49	0.66	0.17	0.42	0.25	0.56	0.31	0.47	0.10	0.79	0.69	0.58	0.36	0.64	0.27
U.S. (excluding CZ 8)	**0.66**	**0.59**	**0.77**	**0.18**	**0.61**	**0.47**	**0.69**	**0.22**	**0.68**	**0.34**	**0.85**	**0.52**	**0.61**	**0.47**	**0.69**	**0.23**

Table 2 (continued)

(c) Aspect ratio R=2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.45	0.43	0.48	0.05	0.42	0.39	0.44	0.06	0.48	0.36	0.62	0.26	0.42	0.38	0.45	0.07
2A (Houston, TX)	0.45	0.43	0.48	0.06	0.42	0.38	0.44	0.07	0.47	0.32	0.63	0.31	0.41	0.37	0.45	0.07
2B (Phoenix, AZ)	0.49	0.44	0.52	0.08	0.41	0.37	0.44	0.07	0.51	0.28	0.70	0.42	0.41	0.36	0.45	0.09
3A (Memphis, TN)	0.46	0.44	0.48	0.03	0.41	0.37	0.45	0.08	0.47	0.27	0.63	0.36	0.41	0.36	0.45	0.10
3B (El Paso, TX)	0.50	0.46	0.53	0.07	0.42	0.39	0.46	0.07	0.51	0.30	0.68	0.38	0.42	0.38	0.47	0.09
BU (Burbank, CA)	0.48	0.45	0.50	0.05	0.42	0.38	0.47	0.08	0.50	0.28	0.67	0.39	0.43	0.38	0.47	0.09
FR (Fresno, CA)	0.47	0.43	0.52	0.09	0.42	0.38	0.45	0.07	0.50	0.28	0.71	0.43	0.42	0.39	0.45	0.06
3C (San Francisco, CA)	0.46	0.44	0.50	0.06	0.42	0.36	0.47	0.11	0.48	0.26	0.66	0.41	0.42	0.37	0.45	0.07
4A (Baltimore, MD)	0.46	0.43	0.47	0.05	0.40	0.30	0.44	0.14	0.45	0.24	0.62	0.38	0.40	0.34	0.44	0.10
4B (Albuquerque, NM)	0.50	0.45	0.54	0.09	0.41	0.36	0.45	0.09	0.50	0.26	0.68	0.42	0.41	0.36	0.47	0.11
4C (Seattle, WA)	0.44	0.42	0.46	0.04	0.40	0.35	0.44	0.09	0.43	0.21	0.65	0.44	0.39	0.33	0.44	0.11
5A (Chicago, IL)	0.45	0.43	0.46	0.02	0.40	0.34	0.43	0.09	0.44	0.23	0.60	0.37	0.40	0.34	0.44	0.10
5B (Boise, ID)	0.47	0.43	0.52	0.09	0.39	0.33	0.43	0.10	0.47	0.21	0.69	0.48	0.39	0.34	0.45	0.10
6A (Burlington, VT)	0.44	0.42	0.46	0.04	0.39	0.33	0.42	0.09	0.44	0.22	0.60	0.38	0.39	0.34	0.43	0.08
6B (Helena, MT)	0.46	0.44	0.49	0.04	0.38	0.32	0.42	0.10	0.44	0.18	0.69	0.50	0.37	0.29	0.43	0.14
7 (Duluth, MN)	0.45	0.43	0.47	0.04	0.38	0.32	0.42	0.10	0.43	0.20	0.63	0.43	0.38	0.33	0.42	0.09
8 (Fairbanks, AK)	0.40	0.33	0.45	0.12	0.26	0.15	0.36	0.20	0.28	0.06	0.51	0.45	0.38	0.23	0.42	0.19
U.S. (excluding CZ 8)	**0.46**	**0.42**	**0.54**	**0.12**	**0.40**	**0.30**	**0.47**	**0.17**	**0.47**	**0.18**	**0.71**	**0.52**	**0.40**	**0.29**	**0.47**	**0.18**

Table 2 (continued)

(d) Aspect ratio R=10

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.13	0.12	0.13	0.01	0.11	0.10	0.11	0.02	0.13	0.08	0.19	0.11	0.11	0.10	0.12	0.02
2A (Houston, TX)	0.13	0.12	0.13	0.01	0.11	0.09	0.11	0.02	0.13	0.07	0.18	0.11	0.11	0.09	0.11	0.02
2B (Phoenix, AZ)	0.14	0.14	0.14	0.01	0.10	0.09	0.11	0.02	0.14	0.06	0.25	0.19	0.10	0.09	0.11	0.03
3A (Memphis, TN)	0.13	0.12	0.13	0.01	0.11	0.10	0.12	0.03	0.13	0.06	0.19	0.13	0.11	0.09	0.12	0.03
3B (El Paso, TX)	0.14	0.14	0.16	0.02	0.11	0.10	0.12	0.03	0.15	0.06	0.25	0.18	0.11	0.10	0.13	0.03
BU (Burbank, CA)	0.14	0.12	0.15	0.02	0.11	0.10	0.13	0.03	0.14	0.06	0.23	0.17	0.11	0.09	0.12	0.03
FR (Fresno, CA)	0.13	0.11	0.15	0.04	0.11	0.10	0.12	0.02	0.14	0.06	0.24	0.17	0.11	0.10	0.12	0.02
3C (San Francisco, CA)	0.13	0.12	0.14	0.02	0.11	0.09	0.12	0.03	0.13	0.06	0.21	0.16	0.11	0.10	0.12	0.02
4A (Baltimore, MD)	0.13	0.12	0.13	0.01	0.10	0.07	0.11	0.04	0.12	0.05	0.19	0.14	0.10	0.09	0.12	0.03
4B (Albuquerque, NM)	0.14	0.13	0.15	0.02	0.10	0.09	0.12	0.03	0.14	0.06	0.25	0.19	0.11	0.09	0.13	0.04
4C (Seattle, WA)	0.12	0.11	0.13	0.02	0.10	0.09	0.11	0.03	0.10	0.05	0.16	0.11	0.10	0.09	0.12	0.03
5A (Chicago, IL)	0.12	0.11	0.13	0.01	0.10	0.09	0.11	0.03	0.11	0.05	0.18	0.13	0.10	0.09	0.12	0.03
5B (Boise, ID)	0.13	0.11	0.14	0.03	0.10	0.09	0.11	0.03	0.11	0.05	0.20	0.15	0.10	0.08	0.12	0.03
6A (Burlington, VT)	0.12	0.11	0.12	0.01	0.10	0.09	0.11	0.03	0.11	0.05	0.16	0.11	0.10	0.08	0.11	0.03
6B (Helena, MT)	0.13	0.12	0.14	0.02	0.09	0.08	0.10	0.02	0.10	0.04	0.18	0.14	0.09	0.08	0.11	0.03
7 (Duluth, MN)	0.12	0.11	0.13	0.01	0.10	0.08	0.11	0.03	0.10	0.04	0.16	0.12	0.10	0.08	0.11	0.03
8 (Fairbanks, AK)	0.11	0.09	0.12	0.03	0.06	0.04	0.09	0.05	0.06	0.02	0.12	0.10	0.10	0.06	0.11	0.05
U.S. (excluding CZ 8)	**0.13**	**0.11**	**0.16**	**0.05**	**0.10**	**0.07**	**0.13**	**0.06**	**0.12**	**0.04**	**0.25**	**0.21**	**0.10**	**0.08**	**0.13**	**0.05**

Table 3. Beam fraction of global solar radiation incident on an isolated wall facing north, east, south, or west, shown in each of four seasons: winter (Dec-Jan-Feb), spring (Mar-Apr-May), summer (Jun-Jul-Aug), and fall (Sep-Oct-Nov).

	N				E				S				W			
	winter	spring	summer	fall	winter	spring	summer	fall	winter	spring	summer	fall	winter	spring	summer	fall
1A (Miami, FL)	0.00	0.05	0.09	0.00	0.47	0.45	0.35	0.41	0.69	0.34	0.09	0.53	0.47	0.45	0.29	0.38
2A (Houston, TX)	0.00	0.05	0.10	0.00	0.43	0.38	0.40	0.48	0.68	0.35	0.16	0.63	0.47	0.41	0.36	0.49
2B (Phoenix, AZ)	0.00	0.10	0.21	0.01	0.60	0.59	0.56	0.64	0.81	0.54	0.34	0.76	0.60	0.57	0.57	0.62
3A (Memphis, TN)	0.00	0.05	0.10	0.00	0.50	0.45	0.45	0.48	0.75	0.44	0.29	0.65	0.52	0.46	0.44	0.49
3B (El Paso, TX)	0.00	0.08	0.16	0.00	0.59	0.57	0.55	0.60	0.80	0.51	0.30	0.74	0.59	0.55	0.53	0.61
BU (Burbank, CA)	0.00	0.06	0.14	0.00	0.54	0.51	0.54	0.54	0.77	0.49	0.36	0.71	0.53	0.52	0.54	0.54
FR (Fresno, CA)	0.00	0.07	0.20	0.00	0.41	0.52	0.61	0.54	0.67	0.51	0.44	0.71	0.39	0.51	0.61	0.54
3C (San Francisco, CA)	0.00	0.05	0.14	0.00	0.47	0.46	0.48	0.47	0.74	0.49	0.39	0.68	0.49	0.48	0.55	0.51
4A (Baltimore, MD)	0.00	0.05	0.11	0.00	0.56	0.47	0.44	0.48	0.77	0.50	0.31	0.67	0.52	0.45	0.43	0.48
4B (Albuquerque, NM)	0.00	0.07	0.19	0.00	0.62	0.59	0.60	0.63	0.83	0.55	0.38	0.77	0.64	0.54	0.53	0.62
4C (Seattle, WA)	0.00	0.04	0.11	0.00	0.37	0.38	0.47	0.44	0.69	0.47	0.45	0.64	0.40	0.39	0.48	0.46
5A (Chicago, IL)	0.00	0.04	0.09	0.00	0.45	0.43	0.43	0.47	0.73	0.47	0.33	0.64	0.46	0.41	0.41	0.43
5B (Boise, ID)	0.00	0.07	0.20	0.00	0.47	0.53	0.61	0.61	0.74	0.55	0.52	0.76	0.47	0.49	0.60	0.58
6A (Burlington, VT)	0.00	0.05	0.12	0.00	0.42	0.47	0.44	0.41	0.68	0.50	0.37	0.61	0.38	0.46	0.45	0.41
6B (Helena, MT)	0.00	0.08	0.17	0.00	0.52	0.50	0.58	0.55	0.80	0.55	0.50	0.74	0.57	0.50	0.54	0.55
7 (Duluth, MN)	0.00	0.08	0.13	0.01	0.47	0.49	0.46	0.44	0.76	0.55	0.43	0.66	0.49	0.50	0.48	0.48
8 (Fairbanks, AK)	0.00	0.20	0.31	0.02	0.73	0.65	0.59	0.63	0.85	0.67	0.51	0.73	0.28	0.46	0.35	0.34

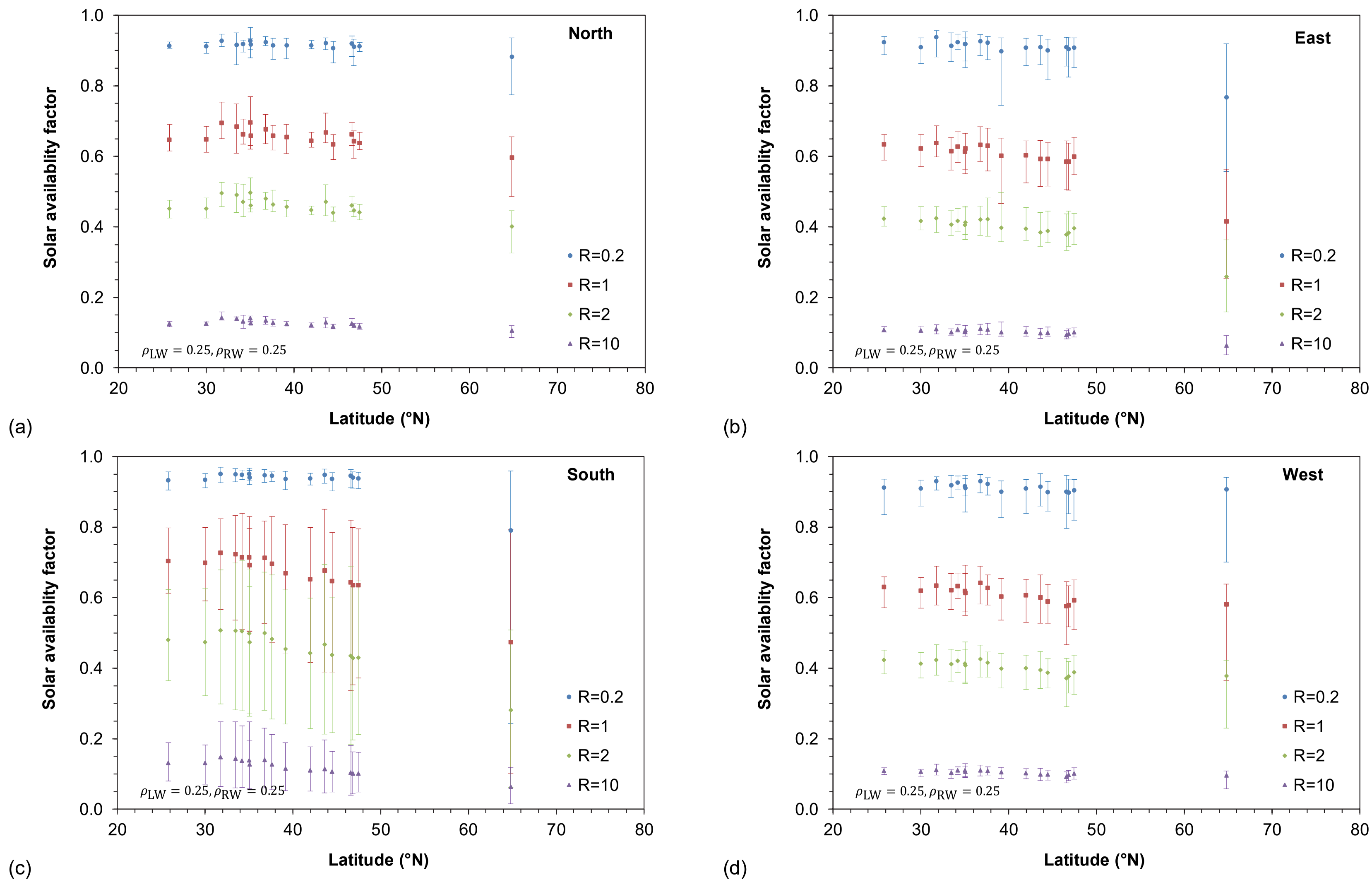


Figure 4. Monthly SAF versus latitude and canyon aspect ratio R for (a) north, (b) east, (c) south, or (d) west conventional central wall (ρ=0.25) facing conventional neighboring wall (ρ=0.25). Marker is annual mean; bars bound annual minimum and maximum values.

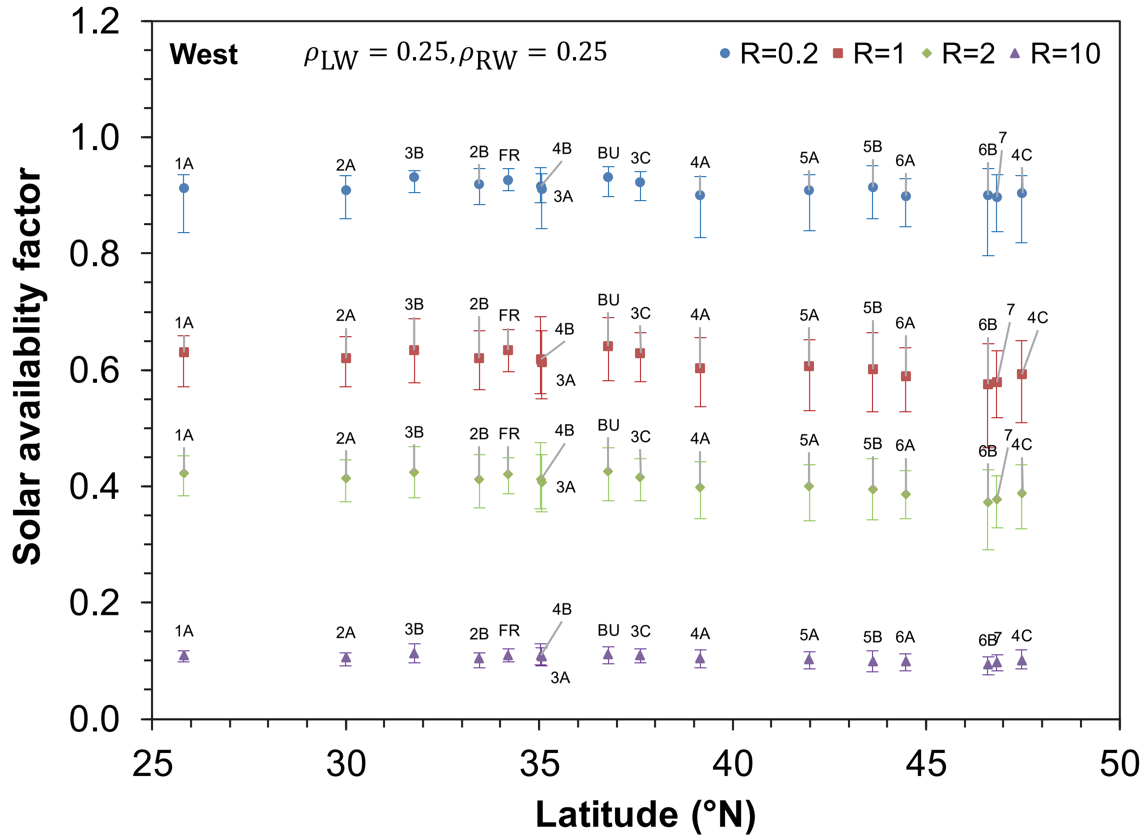


Figure 5. Closeup of mainland U.S. section of Figure 4d, labeling locations to identify effect of zone subtype (A=moist, B=dry, or C=marine) on SAF.

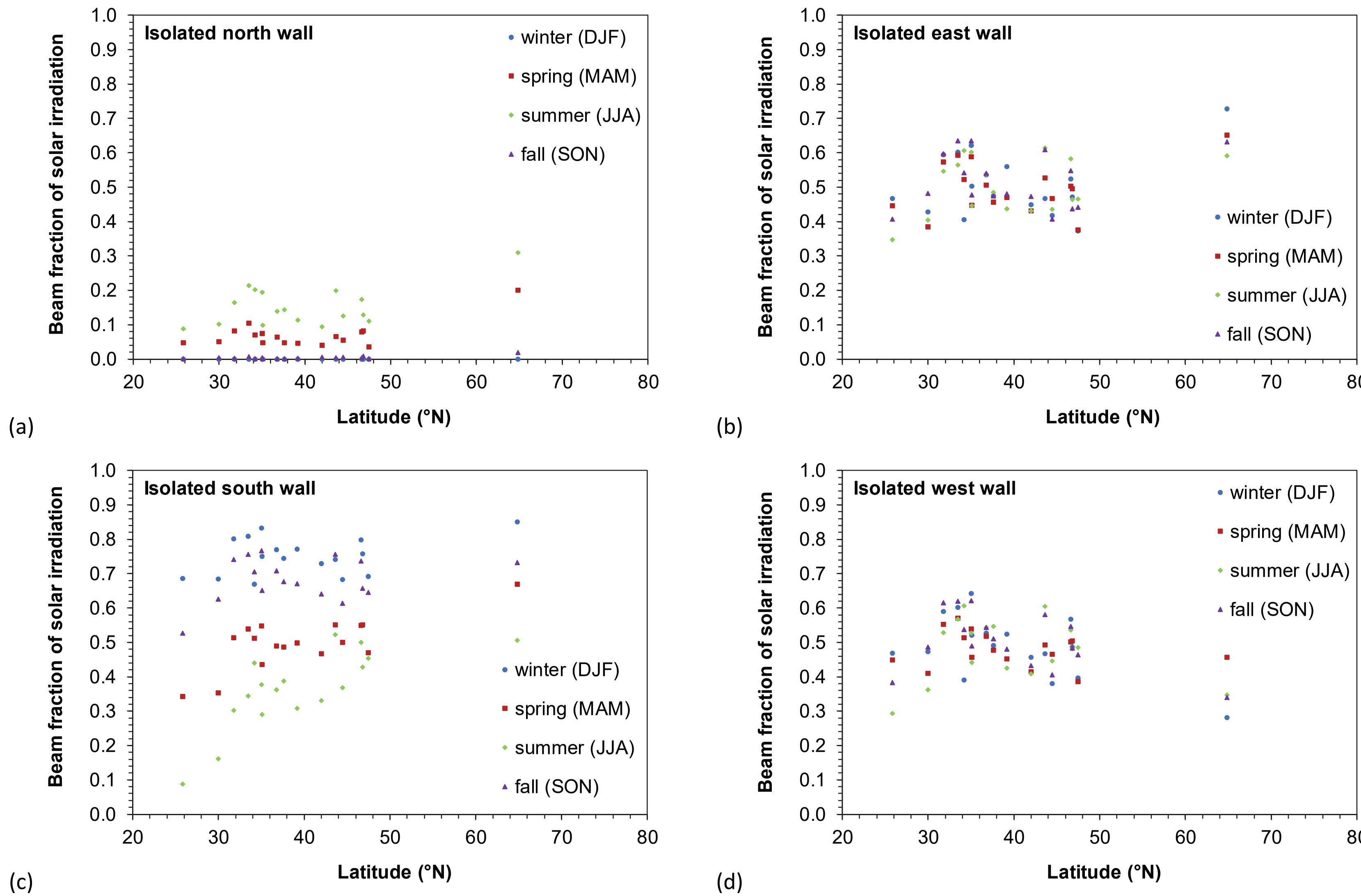


Figure 6. Variation with latitude and season of the beam fraction of global solar radiation incident on an isolated wall facing (a) north, (b) east, (c) south, or (d) west. Winter is Dec-Jan-Feb, spring is Mar-Apr-May, summer is Jun-Jul-Aug, and fall is Sep-Oct-Nov.

Table 4. Annual mean, minimum, and maximum values of monthly SAF in mainland U.S. (all zones except 8) for a north (N), east (E), south (S), or west (W) central wall versus aspect ratio R in four scenarios: (a) conventional central wall (ρ=0.25) with conventional neighboring wall (ρ=0.25); (b) conventional central wall (ρ=0.25) with cool neighboring wall (ρ=0.60); (c) cool central wall (ρ=0.60) with conventional neighboring wall (ρ=0.25); or (d) cool central wall (ρ=0.60) with cool neighboring wall (ρ=0.60). Values are reported as mean followed by (min to max).

(a) Scenario 1: conventional central wall (ρ=0.25) with conventional neighboring wall (ρ=0.25)				
	N	E	S	W
R=0.2	0.92 (0.86 - 0.97)	0.91 (0.74 - 0.96)	0.94 (0.90 - 0.97)	0.91 (0.80 - 0.95)
R=1	0.66 (0.59 - 0.77)	0.61 (0.47 - 0.69)	0.68 (0.34 - 0.85)	0.61 (0.47 - 0.69)
R=2	0.46 (0.42 - 0.54)	0.40 (0.30 - 0.47)	0.47 (0.18 - 0.71)	0.40 (0.29 - 0.47)
R=10	0.13 (0.11 - 0.16)	0.10 (0.07 - 0.13)	0.12 (0.04 - 0.25)	0.10 (0.08 - 0.13)
(b) Scenario 2: conventional central wall (ρ=0.25) with cool neighboring wall (ρ=0.60)				
	N	E	S	W
R=0.2	1.01 (0.89 - 1.25)	0.95 (0.77 - 0.99)	0.96 (0.91 - 0.98)	0.95 (0.82 - 0.99)
R=1	0.92 (0.70 - 1.37)	0.70 (0.53 - 0.80)	0.73 (0.35 - 0.88)	0.70 (0.53 - 0.81)
R=2	0.71 (0.52 - 1.00)	0.49 (0.36 - 0.58)	0.52 (0.20 - 0.76)	0.49 (0.35 - 0.59)
R=10	0.21 (0.16 - 0.28)	0.14 (0.10 - 0.17)	0.14 (0.05 - 0.30)	0.14 (0.10 - 0.17)
(c) Scenario 3: cool central wall (ρ=0.60) with conventional neighboring wall (ρ=0.25)				
	N	E	S	W
R=0.2	0.92 (0.86 - 0.97)	0.92 (0.75 - 0.96)	0.95 (0.91 - 0.97)	0.92 (0.80 - 0.95)
R=1	0.67 (0.60 - 0.78)	0.62 (0.47 - 0.70)	0.70 (0.34 - 0.87)	0.62 (0.47 - 0.70)
R=2	0.47 (0.43 - 0.55)	0.42 (0.31 - 0.48)	0.49 (0.19 - 0.73)	0.42 (0.30 - 0.49)
R=10	0.13 (0.12 - 0.17)	0.11 (0.08 - 0.14)	0.13 (0.04 - 0.26)	0.11 (0.08 - 0.14)
(d) Scenario 4: cool central wall (ρ=0.60) with cool neighboring wall (ρ=0.60)				
	N	E	S	W
R=0.2	1.02 (0.89 - 1.26)	0.95 (0.77 - 1.00)	0.96 (0.92 - 0.98)	0.95 (0.83 - 0.99)
R=1	0.94 (0.72 - 1.39)	0.72 (0.55 - 0.82)	0.75 (0.37 - 0.91)	0.72 (0.55 - 0.83)
R=2	0.73 (0.55 - 1.01)	0.52 (0.38 - 0.61)	0.55 (0.21 - 0.81)	0.52 (0.37 - 0.62)
R=10	0.22 (0.17 - 0.29)	0.15 (0.11 - 0.19)	0.16 (0.05 - 0.33)	0.15 (0.11 - 0.19)

4.2 Monthly SAF in Fresno

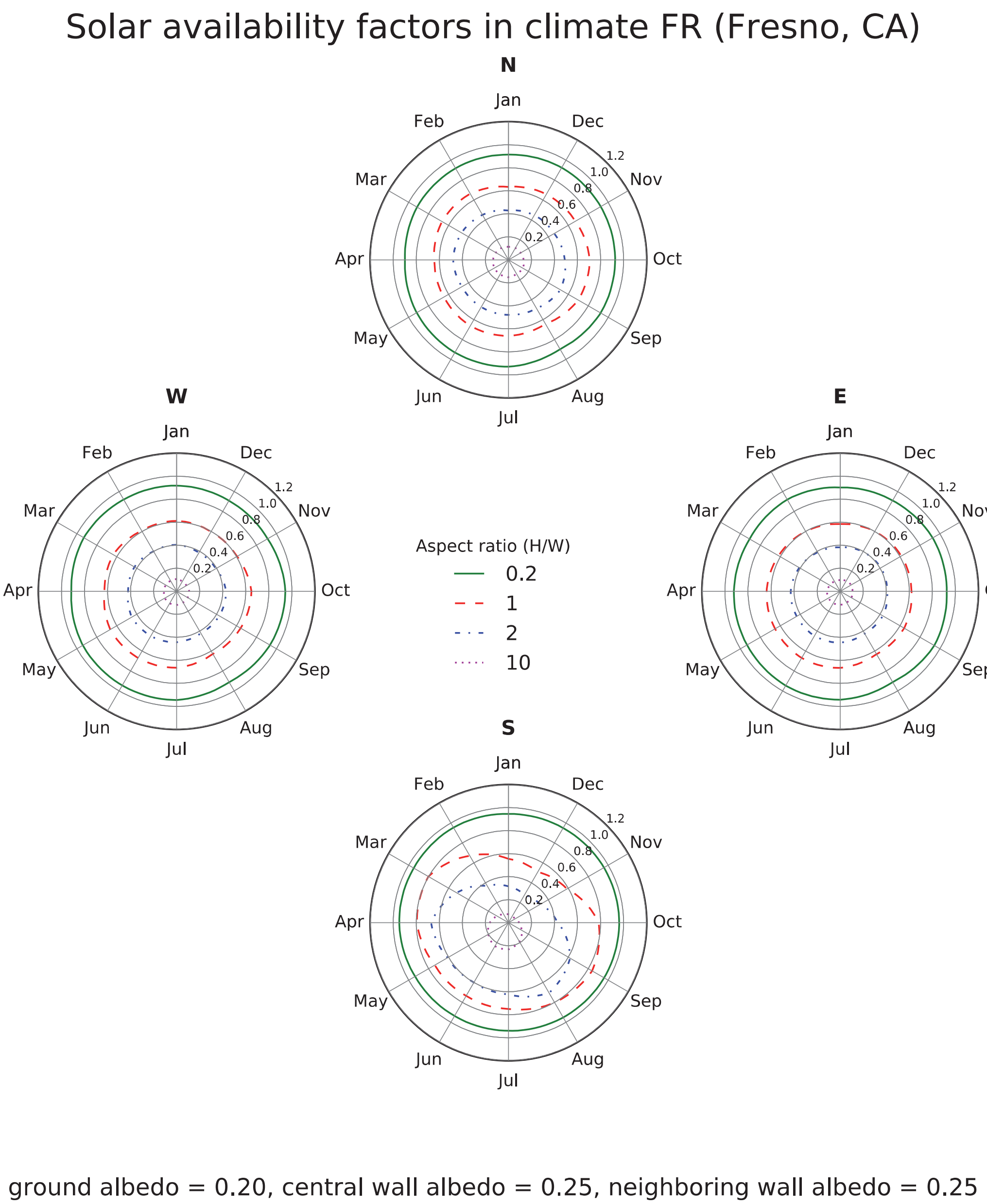
Trends in monthly SAF are illustrated for Fresno, CA in Figure 7. Variation of monthly SAF in Fresno with central wall orientation (N, E, S, or W) and aspect ratio (0.2, 1, 2, or 10) is plotted for Scenario 1 (conventional central wall with conventional neighboring wall) in Figure 7a, and for Scenario 2 (conventional central wall with cool neighboring wall) in Figure 7b.

Analogous plots spanning all 17 climates are presented in Electronic Supplementary Material (ESM) Figure C-1 and ESM Figure C-2 of ESM Appendix C.

In Scenario 1, monthly SAFs in Fresno for the set of north, east, and west central walls range annually from 0.90 to 0.95 for R=0.2, 0.58 to 0.71 for R=1, 0.38 to 0.52 for R=2, and 0.10 to 0.15 for R=10. Ranges for the south central wall are in some cases wider: 0.94 to 0.96 for R=0.2, 0.51 to 0.84 for R=1, 0.28 to 0.71 for R=2, and 0.06 to 0.24 for R=10 (row "FR" in panels a - d of Table 2).

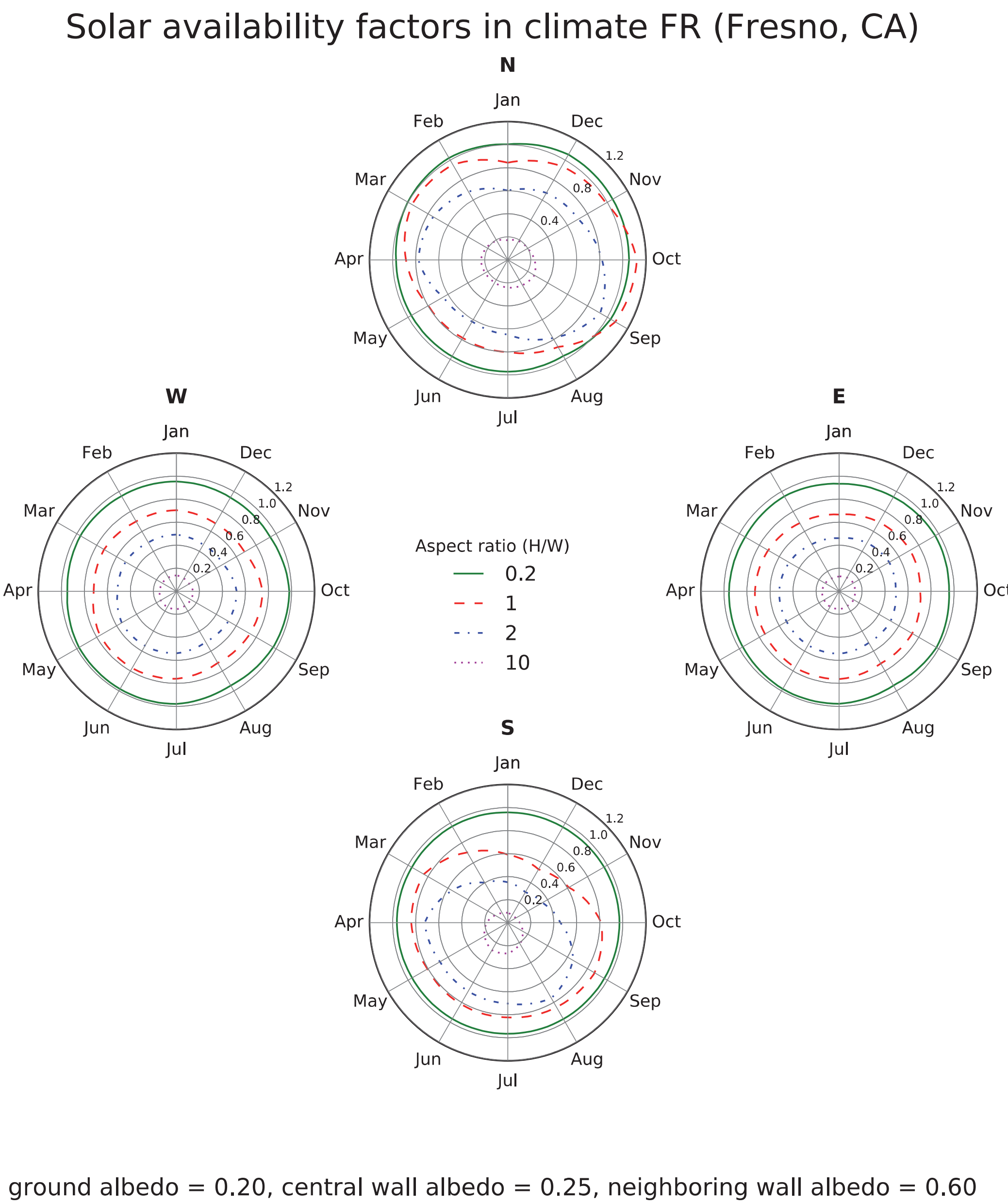
Eq. (3) predicts that for canyon aspect ratios of 0.2, 1, 2, or 10, the sun-facing wall is unshaded when the solar altitude angle $\alpha = 90° - \theta_z$ exceeds 11.3°, 45.0°, 63.4°, or 84.3°, respectively. [It will also be unshaded at lower solar altitudes that satisfy Eq. (2).] The high values of Fresno monthly SAF for R=0.2 (0.90 to 0.96 over all four orientations) in Scenario 1 result from minimal shading of the sun-facing wall. Inspection of the Fresno sun path shows that across the year, the solar altitude angle exceeds 11.3° within about an hour of sunrise, and remains above that value until about an hour before sunset (Figure 8). Monthly SAFs diminish as the aspect ratio grows because the sun-facing wall spends more time in the shade.

Seasonal variations in monthly SAF are greatest for south central walls (Figure 7a) because the Fresno midday sun is much higher (and midday shadows are much shorter) in summer than in winter (Figure 8). For example, the solar altitude angle at noon on June 21 (summer solstice) is 76.7°, while that on December 21 (winter solstice) is 29.8°.



(a)

Figure 7. Monthly SAFs for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) with (a) conventional neighboring wall (ρ=0.25) or (b) cool neighboring wall (ρ=0.60). Results shown for aspect ratios 0.2, 1, 2, and 10 in Fresno, CA.



(b)

Figure 7 (continued)

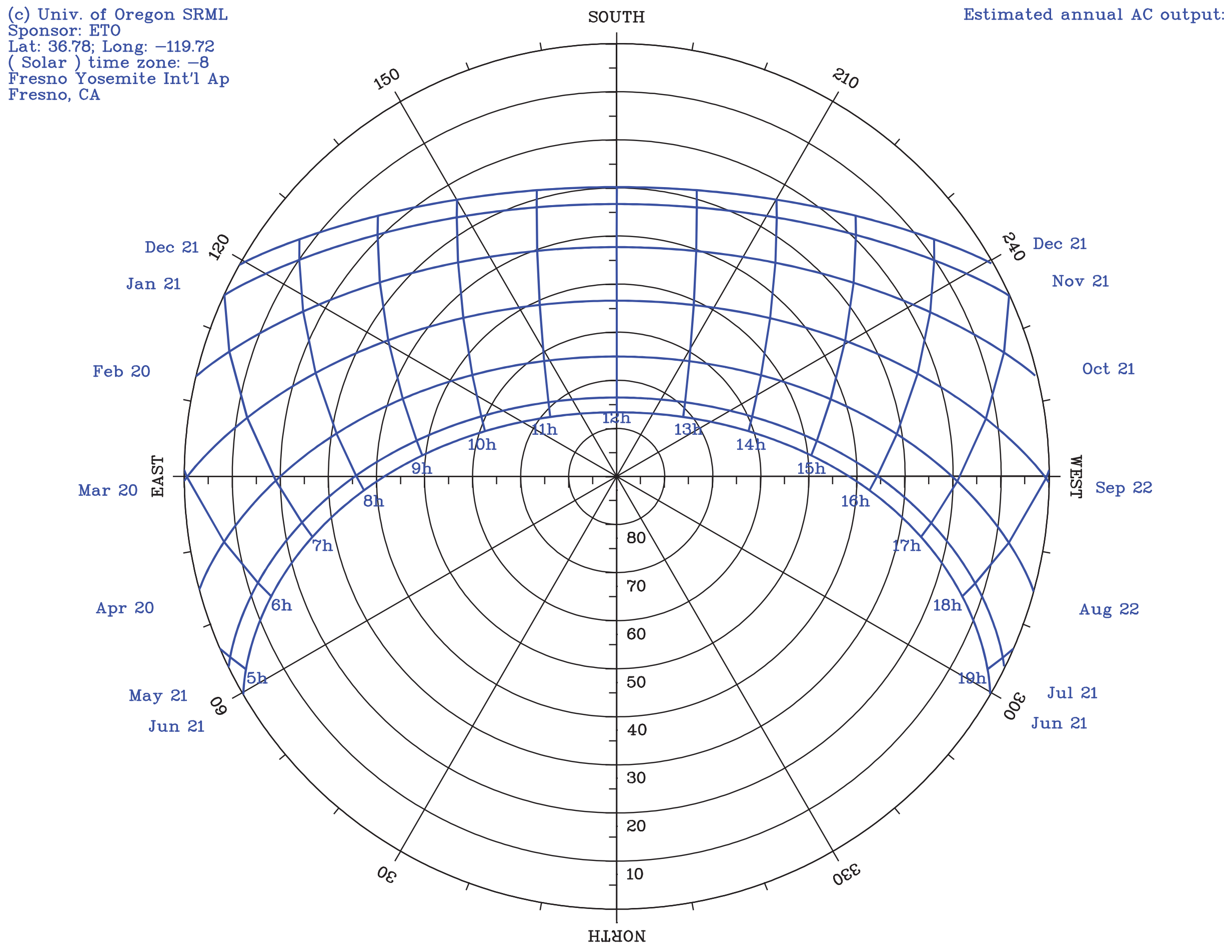


Figure 8. Solar path in climate FR (Fresno, CA). Source: University of Oregon (2018)

4.3 Increase in monthly SAF in Fresno

Figure 9 plots by central wall orientation and aspect ratio the percentage increases in monthly SAF of a conventional central wall in Fresno upon raising the albedo of its neighboring wall to 0.60 (cool) from 0.25 (conventional). This represents the shift to scenario 2 from scenario 1. Analogous graphs spanning all 17 climates are presented in ESM Figure D-1 of ESM Appendix D.

Percentage increases in monthly SAF in Fresno for the set of east, south, and west central walls range annually from 0.9 to 4.1 for R=0.2, 3.6 to 15.3 for R=1, 14.5 to 23.4 for R=2, and 11.0 to 32.9 for R=10. Ranges for the north central wall are wider: 4.2 to 14.2 for R=0.2, 18.4 to 59.1 for R=1, 30.7 to 77.9 for R=2, and 49.4 to 85.4 for R=10 (row "FR" in panels a - d of Table 5).

Percentage increases in Fresno monthly SAF upon raising neighboring wall albedo are greatest for north central walls (Figure 9) because a north wall, receiving little beam sunlight and facing a well-illuminated south wall, receives a higher fraction of its irradiance via reflection that do walls pointing east, south, or west. Between March 20 (spring equinox) and Sep 22 (fall equinox) in Fresno, the sun is 0 to 30° north of east for up to about 4 hours after sunrise, and 0 to 30° north of west for up to about 4 hours before sunset; at all other hours of the year, the sun lies between east and west, at least partially illuminating the south wall.

4.4 Application of monthly SAFs to cool-wall energy savings simulated for an isolated central building

The results for Fresno can illustrate the application of SAF to adjust cool-wall cooling energy savings and heating energy penalties for shading and reflection by a neighboring building. Consider a neighborhood of two-story single-family homes, each 6 m high (neglecting roof pitch). Assume the central home is on the west side of a residential street, with its front neighbor across the street (30 m east; $R = \frac{6}{30} = 0.2$), its rear neighbor across a pair of back yards (6 m west; $R = \frac{6}{6} = 1$), and its side neighbors across narrow side yards (3 m north and 3 m south; $R = \frac{6}{3} = 2$) (Figure 10). Over the course of the year, the monthly SAF for the front (east) wall will vary from 0.90 to 0.95 (mean 0.92, range 0.04) (Table 2a). Meanwhile, that for the back (west) wall will vary from 0.60 to 0.67 (mean 0.63, range 0.07) (Table 2b); that for the right (south) wall will vary from 0.27 to 0.71 (mean 0.50, range 0.43) (Table 2c); and that for the left (north) wall will vary from 0.43 to 0.52 (mean 0.47, range 0.09) (Table 2c). Since the ranges for the east, west, and north walls (0.04, 0.07, and 0.06) are narrow, we can apply their annual mean values of monthly SAF (0.92, 0.63, and 0.47) to the cooling savings, heating penalty, and annual metrics based on these two terms, such as annual HVAC energy cost savings and annual HVAC source energy savings.

The SAF range for the south wall (0.42) is substantially greater, warranting inspection of the south-wall plot in Figure 7a. With aspect ratio 2 (dashed-dotted blue line), monthly SAF for the south wall ranges from about 0.38 to 0.58 between November and March (heating season), and from about 0.68 to 0.71 between May and September (cooling season). This suggests applying a mean SAF of about 0.50 to the heating penalty, and a mean SAF of about 0.70 to the cooling savings. Since the cooling-season mean SAF exceeds the heating-season mean SAF—as it generally will for an east, west, or south wall, because the sun is highest in summer—we can scale annual HVAC energy cost or source energy savings at the south wall by applying its annual mean SAF (0.50). This will underestimate the cooling savings, overestimate the heating penalty, and therefore underestimate the annual HVAC savings, but is conservative and convenient.[1]

Therefore, in this example we would apply SAFs of 0.47 (north), 0.92 (east), 0.50 (south), and 0.63 (west) to the cool-wall annual HVAC savings computed for an isolated central building.

[1] Given the isolated-wall annual heating energy penalty and annual cooling energy savings, we could instead scale the former by the winter SAF and the latter by the summer SAF, then sum the scaled values to estimate annual HVAC savings more accurately. This approach assumes that fan energy uses in the heating and cooling seasons are folded into the annual heating and annual cooling energy uses, respectively.

Assume the home is 15 m long (north-south), 10 m wide (east-west), and 6 m high (neglecting roof pitch), with a 2 m² door and 15 m² of windows each on the east and west facades, and 10 m² of windows each on the north and south facades (Figure 11). The net wall area (gross wall area minus openings) will be 15 m × 6 m – 2 m² - 15 m² = 73 m² on the east facade and on the west facade, and 10 m × 6 m – 10 m² = 50 m² on the north facade and on the south facade.

We obtain isolated-wall annual HVAC energy cost savings intensity ($/m² wall) at each wall (row a in Table 6) from Rosado and Levinson (2018) assuming that the building was constructed 30 years ago (in 1988) and is best represented by that study's "older" vintage prototype. Rows b – f in Table 6 show how to scale these savings intensities by net wall area and SAF to compute the annual HVAC energy cost savings ($) before and after adjusting for shading and reflection by neighboring buildings. We find that shading and reflection reduce the building's total annual savings by 31%, to $118 from $173.

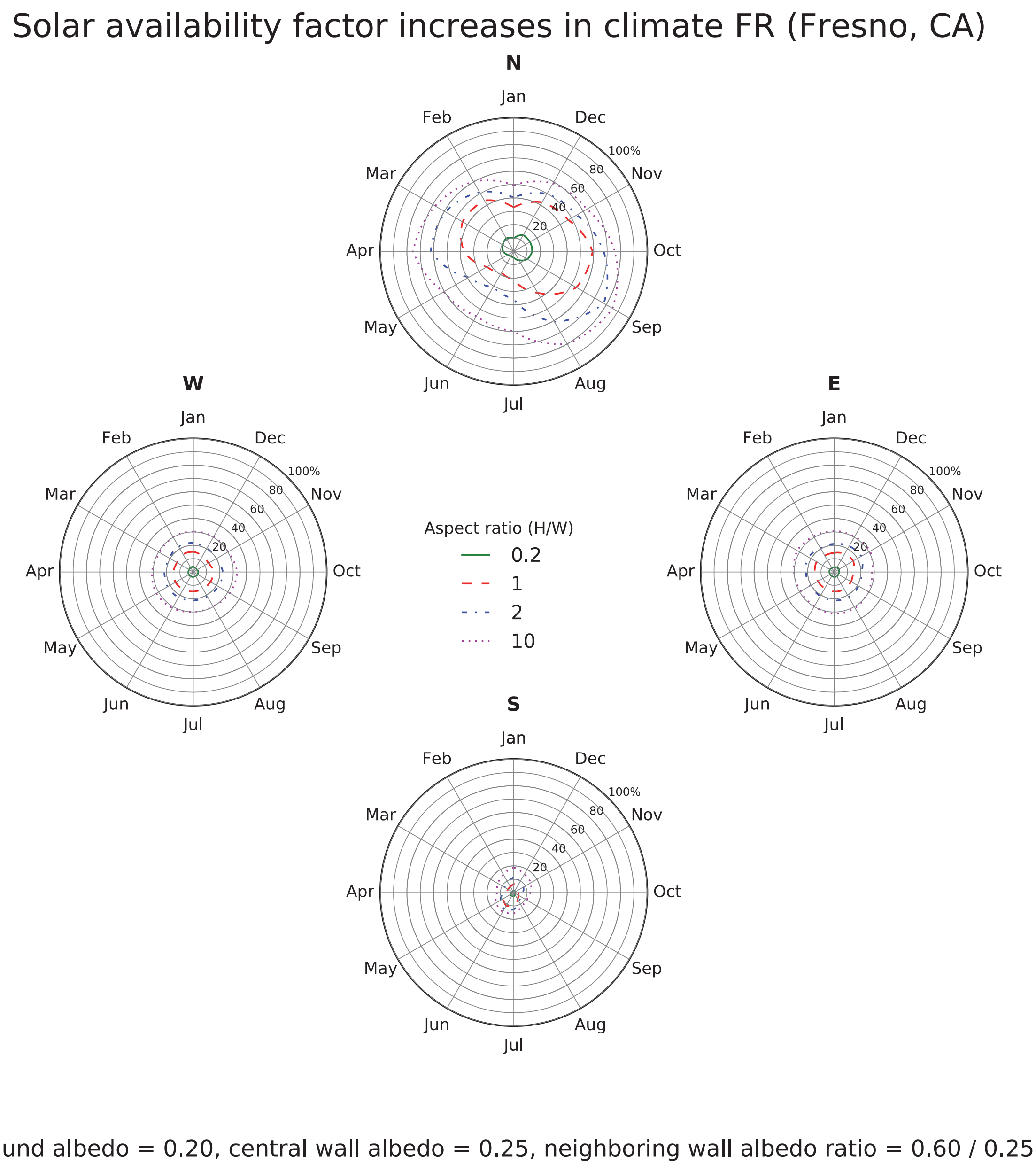


Figure 9. Percentage increases in monthly SAFs for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) upon raising the albedo of its neighboring wall to 0.60 (cool) from 0.25 (conventional). Results shown for aspect ratios 0.2, 1, 2, and 10 in Fresno, CA.

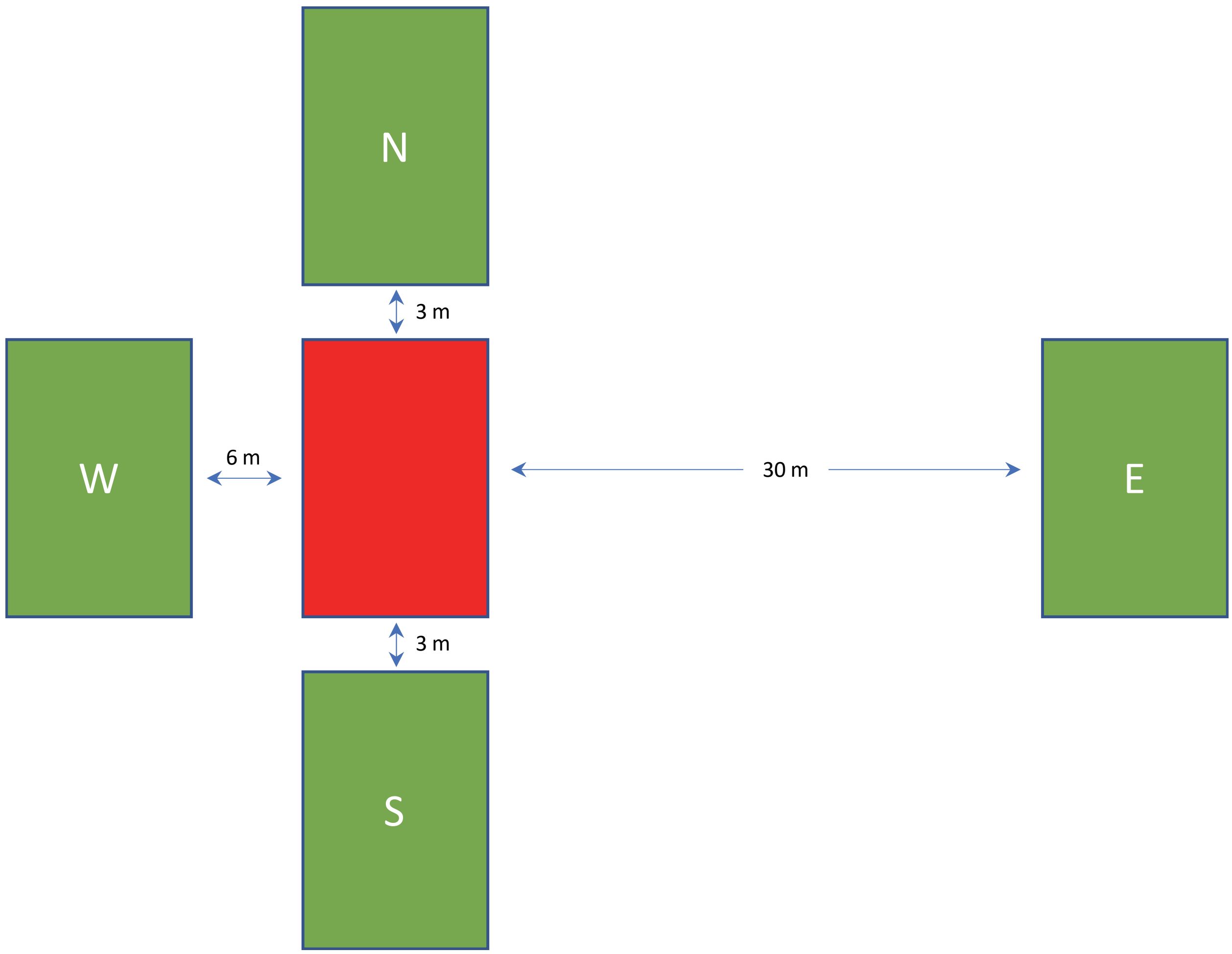


Figure 10. A single-family home (central building, in red) surrounded by its neighbors (in green). Each building is 10 m wide, 15 m long, and 6 m high (neglecting roof pitch).

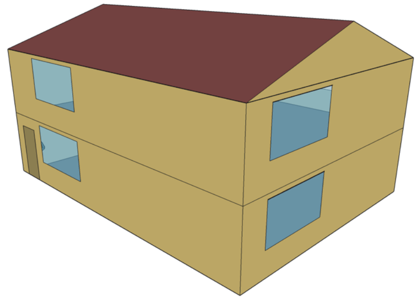


Figure 11. Sketch of two-story single-family home. Source: Rosado and Levinson (2018).

Table 5. Annual mean, minimum, maximum, and range (maximum – minimum) percentage increases in monthly SAF for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) upon raising the albedo of its neighboring wall to 0.60 (cool) from 0.25 (conventional). Results shown by climate for aspect ratio of (a) R=0.2, (b) R=1, (c) R=2, or (d) R=10.

(a) Aspect ratio R=0.2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	7.5	3.2	13.6	10.3	3.6	3.1	4.3	1.2	2.3	1.0	4.1	3.2	3.8	3.1	4.3	1.2
2A (Houston, TX)	8.1	3.4	13.5	10.1	3.8	3.4	4.1	0.7	2.1	1.0	3.9	2.9	3.6	3.3	4.0	0.7
2B (Phoenix, AZ)	12.4	3.6	24.1	20.5	3.6	3.3	4.0	0.7	1.6	0.5	3.6	3.0	3.7	3.4	4.1	0.7
3A (Memphis, TN)	9.6	4.0	17.5	13.5	3.7	3.4	4.0	0.6	1.8	0.8	3.3	2.5	3.6	3.4	3.9	0.6
3B (El Paso, TX)	11.8	3.6	21.7	18.1	3.6	3.3	4.1	0.8	1.7	0.6	3.7	3.1	3.8	3.3	4.1	0.8
BU (Burbank, CA)	10.8	4.0	20.0	16.0	3.7	3.4	4.0	0.6	1.6	0.7	3.3	2.6	3.6	3.4	4.0	0.6
FR (Fresno, CA)	9.5	4.2	14.2	10.0	3.7	3.4	4.1	0.7	1.7	0.9	3.1	2.2	3.7	3.3	3.9	0.6
3C (San Francisco, CA)	10.0	4.4	18.5	14.0	3.9	3.4	4.4	1.0	1.6	0.7	3.0	2.2	3.5	3.0	4.0	0.9
4A (Baltimore, MD)	10.4	4.4	18.2	13.9	3.6	3.2	4.2	0.9	1.7	0.7	3.0	2.3	3.8	3.3	4.2	0.9
4B (Albuquerque, NM)	13.5	3.8	29.9	26.0	3.4	3.0	4.1	1.0	1.5	0.4	3.4	3.0	4.0	3.3	4.4	1.1
4C (Seattle, WA)	9.2	5.3	14.0	8.7	3.8	3.4	4.3	1.0	1.6	1.0	2.5	1.6	3.6	3.1	4.0	0.9
5A (Chicago, IL)	9.4	4.5	16.5	11.9	3.6	3.4	3.8	0.5	1.7	0.8	2.9	2.1	3.8	3.5	4.0	0.5
5B (Boise, ID)	11.6	4.9	19.3	14.4	3.6	3.2	4.0	0.8	1.4	0.7	2.7	2.0	3.8	3.4	4.3	0.8
6A (Burlington, VT)	9.0	4.5	15.3	10.7	3.7	3.4	3.9	0.5	1.7	0.9	2.9	2.1	3.7	3.4	4.0	0.5
6B (Helena, MT)	12.3	5.0	21.8	16.7	3.7	3.3	4.2	0.9	1.4	0.6	2.6	2.0	3.7	3.2	4.1	0.9
7 (Duluth, MN)	10.5	4.9	18.2	13.3	3.8	3.5	4.1	0.6	1.5	0.7	2.7	2.0	3.6	3.3	3.9	0.6
8 (Fairbanks, AK)	11.2	5.1	20.7	15.7	2.5	1.9	3.8	1.9	1.4	0.7	2.7	2.0	5.6	3.6	7.1	3.5

Table 5 (continued)

(b) Aspect ratio R=1

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	31.9	12.4	54.1	41.6	14.3	12.8	16.5	3.7	8.6	4.0	16.9	13.0	15.1	13.1	16.8	3.7
2A (Houston, TX)	33.7	13.6	51.7	38.1	14.9	13.4	16.1	2.7	7.9	4.1	15.4	11.3	14.5	13.3	16.0	2.6
2B (Phoenix, AZ)	47.1	15.6	72.8	57.2	14.5	13.6	15.4	1.8	5.9	2.9	13.3	10.3	14.8	14.0	15.7	1.8
3A (Memphis, TN)	37.5	17.0	55.2	38.3	14.7	13.9	15.8	1.9	6.7	3.9	12.4	8.5	14.6	13.6	15.4	1.8
3B (El Paso, TX)	45.8	14.5	74.2	59.7	14.4	13.9	15.6	1.7	6.3	2.9	14.2	11.4	14.9	13.8	15.5	1.7
BU (Burbank, CA)	41.8	16.9	63.6	46.7	15.0	14.0	15.8	1.8	6.2	3.4	12.3	9.0	14.4	13.6	15.3	1.7
FR (Fresno, CA)	38.3	18.4	59.1	40.7	14.7	14.0	16.5	2.5	6.2	3.6	11.3	7.7	14.6	13.1	15.3	2.3
3C (San Francisco, CA)	38.8	19.3	52.6	33.3	15.5	14.0	17.2	3.1	6.2	4.1	10.8	6.8	13.9	12.5	15.4	2.9
4A (Baltimore, MD)	38.4	18.9	54.0	35.1	14.3	13.4	16.3	2.9	6.4	4.0	11.1	7.2	15.1	13.2	16.1	2.9
4B (Albuquerque, NM)	49.1	16.6	78.5	61.9	13.8	12.7	15.7	3.0	5.6	2.7	12.5	9.8	15.6	13.7	16.8	3.2
4C (Seattle, WA)	33.5	23.9	45.8	22.0	15.0	13.4	16.9	3.5	6.6	4.7	8.9	4.2	14.4	12.7	16.0	3.3
5A (Chicago, IL)	34.4	19.9	46.2	26.3	14.3	13.6	15.2	1.6	6.7	4.6	10.6	6.0	15.1	14.2	15.9	1.7
5B (Boise, ID)	42.2	22.5	64.2	41.7	14.3	13.3	15.3	2.0	5.5	3.3	9.4	6.1	15.1	14.1	16.2	2.1
6A (Burlington, VT)	33.2	20.2	43.7	23.5	14.5	13.6	15.6	1.9	6.8	4.9	10.5	5.6	14.9	13.8	15.8	1.9
6B (Helena, MT)	41.1	22.5	54.4	31.8	14.5	13.4	16.4	3.0	5.6	3.9	9.4	5.5	14.9	13.2	16.1	2.9
7 (Duluth, MN)	36.3	22.4	48.2	25.8	15.1	13.9	16.3	2.4	6.2	4.4	9.5	5.0	14.3	13.2	15.5	2.3
8 (Fairbanks, AK)	32.4	19.3	46.6	27.3	11.8	10.1	15.0	4.9	7.0	4.6	11.2	6.6	18.5	14.4	21.4	6.9

Table 5 (continued)

(c) Aspect ratio R=2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	43.3	17.7	61.6	43.9	20.9	18.9	23.8	4.9	12.6	7.4	25.2	17.7	22.0	19.2	24.2	5.0
2A (Houston, TX)	45.2	20.2	64.3	44.1	21.6	19.8	23.3	3.5	11.6	7.1	22.1	15.0	21.2	19.6	23.1	3.4
2B (Phoenix, AZ)	61.0	24.8	79.3	54.5	21.2	20.0	22.2	2.2	8.7	5.8	17.9	12.1	21.6	20.6	22.8	2.3
3A (Memphis, TN)	49.7	27.1	62.3	35.2	21.4	20.4	22.9	2.5	9.9	7.3	16.5	9.2	21.3	20.0	22.4	2.4
3B (El Paso, TX)	59.3	23.1	80.6	57.5	21.1	20.6	22.4	1.8	9.1	5.7	19.1	13.4	21.7	20.4	22.2	1.7
BU (Burbank, CA)	55.4	27.4	70.5	43.1	21.8	20.6	22.9	2.3	9.1	6.5	16.2	9.7	21.0	19.9	22.2	2.3
FR (Fresno, CA)	52.3	30.7	77.9	47.3	21.4	20.5	23.4	2.9	9.3	5.9	14.5	8.6	21.4	19.5	22.3	2.7
3C (San Francisco, CA)	52.0	31.8	72.4	40.6	22.4	20.5	24.1	3.6	9.2	6.3	14.1	7.8	20.4	18.9	22.4	3.4
4A (Baltimore, MD)	50.3	30.9	61.4	30.4	20.9	19.9	23.3	3.4	9.5	7.5	14.5	7.1	21.9	19.6	23.0	3.3
4B (Albuquerque, NM)	62.7	27.5	84.9	57.4	20.4	18.9	22.8	3.8	8.2	5.4	16.1	10.7	22.5	20.1	24.1	4.0
4C (Seattle, WA)	45.3	35.9	56.0	20.1	21.6	19.7	23.4	3.8	10.3	8.2	12.8	4.6	21.2	19.5	23.2	3.8
5A (Chicago, IL)	46.0	32.7	55.7	23.0	21.0	19.9	22.1	2.2	10.1	8.2	13.8	5.6	21.8	20.7	22.9	2.2
5B (Boise, ID)	55.7	38.6	78.9	40.3	21.1	19.6	22.4	2.8	8.5	5.8	11.7	5.9	21.7	20.4	23.3	2.9
6A (Burlington, VT)	44.7	33.3	54.5	21.2	21.2	19.9	22.7	2.8	10.4	8.4	13.6	5.2	21.6	20.2	23.0	2.8
6B (Helena, MT)	53.7	39.2	65.4	26.2	21.1	19.7	23.0	3.4	8.7	7.0	11.6	4.6	21.8	19.9	23.3	3.3
7 (Duluth, MN)	48.2	38.0	56.3	18.3	21.8	20.3	23.7	3.3	9.6	8.1	12.0	3.8	21.1	19.3	22.5	3.2
8 (Fairbanks, AK)	40.8	26.2	55.0	28.8	18.0	15.7	21.7	6.0	11.7	8.3	17.5	9.2	25.7	21.1	29.2	8.1

Table 5 (continued)

(d) Aspect ratio R=10

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	56.0	26.1	70.2	44.2	30.2	27.8	34.6	6.8	18.2	13.3	35.0	21.7	30.7	26.8	33.3	6.5
2A (Houston, TX)	58.5	37.5	72.8	35.3	31.0	28.9	33.4	4.5	16.5	12.8	24.6	11.7	29.9	27.7	31.9	4.2
2B (Phoenix, AZ)	75.0	49.0	87.5	38.5	30.5	27.8	32.4	4.6	12.9	10.7	18.9	8.2	30.4	28.7	33.4	4.7
3A (Memphis, TN)	62.9	49.7	70.9	21.1	30.6	28.5	33.4	4.9	15.0	13.2	18.6	5.4	30.4	27.8	32.6	4.8
3B (El Paso, TX)	74.0	46.9	87.9	41.0	30.7	29.7	32.1	2.4	13.1	10.7	19.7	9.0	30.3	28.9	31.2	2.3
BU (Burbank, CA)	69.8	53.2	78.6	25.3	30.3	28.7	31.9	3.2	13.6	11.9	17.4	5.5	30.6	29.1	32.2	3.1
FR (Fresno, CA)	66.0	49.4	85.4	36.1	30.3	28.2	32.1	3.9	14.5	11.0	18.8	7.8	30.7	28.9	32.9	4.0
3C (San Francisco, CA)	65.1	55.1	80.7	25.5	32.3	28.7	34.2	5.5	14.5	11.6	16.8	5.2	28.8	27.1	32.3	5.2
4A (Baltimore, MD)	62.2	50.8	70.0	19.2	30.4	29.2	32.8	3.6	15.1	13.3	18.3	4.9	30.5	28.2	31.7	3.5
4B (Albuquerque, NM)	76.6	54.1	92.0	37.9	30.0	28.4	33.2	4.8	12.5	10.2	17.1	6.9	31.0	27.9	32.7	4.8
4C (Seattle, WA)	55.5	45.1	65.1	20.0	31.3	29.2	33.5	4.3	17.0	14.3	20.6	6.3	29.6	27.7	31.7	4.1
5A (Chicago, IL)	57.4	50.7	64.7	13.9	29.5	28.2	31.4	3.2	16.3	14.4	18.3	3.9	31.5	29.6	32.9	3.3
5B (Boise, ID)	67.0	51.0	86.7	35.7	29.3	28.2	31.1	2.9	14.2	10.8	18.2	7.4	31.6	29.8	32.8	3.0
6A (Burlington, VT)	55.5	45.7	63.8	18.1	29.7	27.8	31.6	3.8	16.9	14.6	20.3	5.7	31.3	29.3	33.4	4.0
6B (Helena, MT)	63.9	54.8	74.0	19.2	30.3	28.3	34.0	5.8	14.7	12.6	17.0	4.3	30.7	27.2	32.7	5.5
7 (Duluth, MN)	58.5	51.4	65.1	13.7	31.7	30.0	34.6	4.6	16.0	14.3	18.1	3.8	29.3	26.8	30.9	4.1
8 (Fairbanks, AK)	50.0	35.3	64.0	28.7	26.2	23.2	30.0	6.8	19.0	14.6	26.2	11.7	35.6	30.9	40.0	9.1

Table 6. Scaling annual HVAC energy cost savings simulated for an isolated home in Fresno, CA to account for shading and reflection by neighboring walls.

		N	E	S	W	Total
(a)	Net wall area [m²]	50	73	50	73	246
(b)	Isolated savings intensity [$/m² wall]	0.36	0.84	0.82	0.72	
(c)	Isolated savings [$] = a × b	18	61	41	53	173
(d)	Solar availability factor [-]	0.47	0.92	0.50	0.63	
(e)	Adjusted savings intensity [$/m² wall] = b × d	0.17	0.77	0.41	0.45	
(f)	Adjusted savings [$] = a × e = a × b × d	8.5	56	21	33	118

5 Summary

This study evaluates the solar availability factor (SAF) of a central wall, or ratio of sunlight incident on a wall of the central building in the presence of the neighboring wall to that incident in the absence of the neighboring wall. The theory considers shading and reflection by neighboring buildings, as well as reflection from the ground between the buildings. SAF can be used to scale cool-wall cooling savings, heating penalties, or HVAC savings simulated for an isolated central building (no neighbors) to account for interaction with the neighboring wall.

Monthly values of SAF were evaluated in 17 climates across the United States, including three in California, for north, east, south, and west central walls, over a wide range of canyon aspect ratio (height/width). Results are presented for four representative aspect ratios—0.2, 1, 2, and 10.

SAF in summer (the cooling season) is typically higher than annual mean SAF, while SAF in winter (the heating season) is typically lower than annual mean SAF. Therefore, if a building is cooled in summer and heated (or at least not cooled) in winter, scaling annual isolated-wall savings by the local annual mean SAF should yield a conservative (lower bound) estimate of the savings that will accrue to the central building. Further, since annual mean SAF varies only modestly across the mainland U.S., one can approximate annual mean SAF in any of the mainland U.S. climates simulated here by the mainland-U.S. average for that scenario and orientation (Table 4).

In Fresno, CA, monthly SAF ranges from 0.90 to 0.96 for central walls facing north, east, south, or west when the aspect ratio is 0.2 (two-story single-family homes across a street) and both the central and neighboring walls are conventional (albedo 0.25). These SAFs are close to unity because the sun-facing wall is rarely shaded in a canyon with low aspect ratio. Monthly SAFs decrease as aspect ratio rises, falling to 0.06 – 0.24 at an aspect ratio of 10 (adjacent 10-story buildings on the same side of the street). Seasonal variation in monthly SAF also increases with aspect ratio and is greatest for south central walls.

In Fresno, percentage increases in SAF (equivalent to percentage increases in irradiance) for a central wall upon raising the albedo of a neighboring wall to 0.60 (cool) from 0.25

(conventional) are modest for east, south, and west central walls, ranging 0.9 – 4.1 at aspect ratio 0.2 to 11.0 – 32.9 at aspect ratio 10. Percentage increases for a north central wall are greater because a north wall receives little beam sunlight and faces a well-illuminated south wall.

An example worked for a two-story single-family home in Fresno on the west side of a residential street yields SAFs of 0.47 (north), 0.92 (east), 0.50 (south), and 0.63 (west) to apply to the cool-wall annual HVAC energy savings computed for an isolated central building. Shading and reflection reduce the home's annual HVAC energy cost savings by 31%.

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Appendix A: Derivation of canyon irradiances

A.1 Initial solar powers incident on canyon surfaces

All beam sunlight (power) downwelling through the canyon ceiling,

$$Q_{\mathrm{C,B}} = I_{\mathrm{BH}} \times W \times L, \tag{A-1}$$

will strike either the ground or the sun-facing wall. Therefore, all beam sunlight that enters the canyon, but does not strike the ground, will strike the sun-facing wall. The beam solar power incident on the sun-facing wall (SFW) will be

$$Q_{\mathrm{SFW,B}} = I_{\mathrm{BH}} \times J \times L, \tag{A-2}$$

where ground shadow length (normal to wall)

$$J = \min(H \times \tan\theta_{\mathrm{z}} \times \cos\gamma_{\mathrm{SFW}}\,, W). \tag{A-3}$$

The beam solar power incident on the ground will be

$$Q_{\mathrm{G,B}} = I_{\mathrm{BH}} \times (W - J) \times L, \tag{A-4}$$

and that incident on the sun-opposing wall will be zero.

The diffuse sunlight (power) downwelling through the canyon ceiling,

$$Q_{\mathrm{C,D}} = I_{\mathrm{DH}} \times W \times L, \tag{A-5}$$

will strike the walls and ground in proportion to the view factor from the canyon ceiling to each surface.

Let $Q_{\mathrm{i,B}}$, $Q_{\mathrm{i,D}}$, and $Q_{\mathrm{i}} = Q_{\mathrm{i,B}} + Q_{\mathrm{i,D}}$ represent the initial beam, diffuse, and global solar powers—that is, those downwelling through the canyon ceiling—incident on each canyon surface (LW, RW, or G). Then

$$Q_{\mathrm{i,LW,B}} = Q_{\mathrm{SFW,B}} \text{ if } \cos\gamma_{\mathrm{LW}} > 0\text{, or 0 otherwise;} \tag{A-6}$$

$$Q_{\mathrm{i,RW,B}} = Q_{\mathrm{SFW,B}} \text{ if } \cos\gamma_{\mathrm{RW}} > 0\text{, or 0 otherwise;} \tag{A-7}$$

$$Q_{\mathrm{i,G,B}} = Q_{\mathrm{G,B}}; \tag{A-8}$$

$$Q_{\mathrm{i,LW,D}} = Q_{\mathrm{C,D}} \times F_{\mathrm{C \to LW}}; \tag{A-9}$$

$$Q_{\mathrm{i,RW,D}} = Q_{\mathrm{C,D}} \times F_{\mathrm{C \to RW}}; \tag{A-10}$$

and

$$Q_{\mathrm{i,G,D}} = Q_{\mathrm{C,D}} \times F_{\mathrm{C \to G}}. \tag{A-11}$$

A.2 View factors

The view factor from ceiling to ground is

$$F_{\mathrm{C}\to\mathrm{G}} = \sqrt{1+R^2} - R, \tag{A-12}$$

where canyon aspect ratio $R \equiv H/W$ (Howell 2018, entry C-1).

Since the ceiling does not see itself, $F_{\mathrm{C}\to\mathrm{LW}} + F_{\mathrm{C}\to\mathrm{RW}} + F_{\mathrm{C}\to\mathrm{G}} = 1$; by symmetry, $F_{\mathrm{C}\to\mathrm{LW}} = F_{\mathrm{C}\to\mathrm{RW}}$. Hence the view factor from the ceiling to either wall is

$$F_{\mathrm{C}\to\mathrm{LW}} = F_{\mathrm{C}\to\mathrm{RW}} = (1 - F_{\mathrm{C}\to\mathrm{G}})/2. \tag{A-13}$$

By symmetry, the view factor from the ground to either wall equals that from the ceiling to either wall:

$$F_{\mathrm{G}\to\mathrm{LW}} = F_{\mathrm{G}\to\mathrm{RW}} = F_{\mathrm{C}\to\mathrm{LW}}. \tag{A-14}$$

Applying view factor reciprocity ($A_{\mathrm{X}}\, F_{\mathrm{X}\to\mathrm{Y}} = A_{\mathrm{Y}}\, F_{\mathrm{Y}\to\mathrm{X}}$), the view factor from the left wall to the ground is

$$F_{\mathrm{LW}\to\mathrm{G}} = (A_{\mathrm{G}}/A_{\mathrm{LW}})\, F_{\mathrm{G}\to\mathrm{LW}}, \tag{A-15}$$

where ground area

$$A_{\mathrm{G}} = W \times L \tag{A-16}$$

and left wall area

$$A_{\mathrm{LW}} = H \times L. \tag{A-17}$$

Simplifying,

$$F_{\mathrm{LW}\to\mathrm{G}} = F_{\mathrm{G}\to\mathrm{LW}}/R. \tag{A-18}$$

Similarly, the view factor from the right wall to the ground is

$$F_{\mathrm{RW}\to\mathrm{G}} = F_{\mathrm{G}\to\mathrm{RW}}/R. \tag{A-19}$$

The left wall does not see itself, and by symmetry, its view factor to the ground equals that to the ceiling. Hence, the view factor from the left wall to the right wall is

$$F_{\mathrm{LW}\to\mathrm{RW}} = 1 - (F_{\mathrm{LW}\to\mathrm{G}} + F_{\mathrm{LW}\to\mathrm{C}}) = 1 - 2 \times F_{\mathrm{LW}\to\mathrm{C}}. \tag{A-20}$$

Applying view factor reciprocity,

$$F_{\mathrm{LW}\to\mathrm{C}} = (A_{\mathrm{C}}/A_{\mathrm{LW}})\, F_{\mathrm{C}\to\mathrm{LW}} = F_{\mathrm{C}\to\mathrm{LW}}/R, \tag{A-21}$$

where ceiling area

$$A_{\mathrm{C}} = W \times L. \tag{A-22}$$

Since by symmetry $F_{\mathrm{LW\to RW}} = F_{\mathrm{RW\to LW}}$,

$$F_{\mathrm{LW\to RW}} = F_{\mathrm{RW\to LW}} = 1 - (2/R) \times F_{\mathrm{C\to LW}}. \tag{A-23}$$

Note that each view factor depends only on canyon aspect ratio R.

A.3 Cumulative irradiance incident on left wall

The cumulative solar power that strikes the left wall after no more than two reflections from canyon surfaces will be

$$Q_{\mathrm{LW}} = a \times Q_{\mathrm{i,LW}} + b \times Q_{\mathrm{i,RW}} + c \times Q_{\mathrm{i,G}}, \tag{A-24}$$

where reflection multipliers

$$a = 1 + \rho_{\mathrm{LW}} \times (F_{\mathrm{LW\to G}} \times \rho_{\mathrm{G}} \times F_{\mathrm{G\to LW}} + F_{\mathrm{LW\to RW}} \times \rho_{\mathrm{RW}} \times F_{\mathrm{RW\to LW}}) \tag{A-25}$$

$$b = \rho_{\mathrm{RW}} \times (F_{\mathrm{RW\to LW}} + F_{\mathrm{RW\to G}} \times \rho_{\mathrm{G}} \times F_{\mathrm{G\to LW}}) \tag{A-26}$$

$$c = \rho_{\mathrm{G}} \times (F_{\mathrm{G\to LW}} + F_{\mathrm{G\to RW}} \times \rho_{\mathrm{RW}} \times F_{\mathrm{RW\to LW}}) \tag{A-27}$$

and ρ is albedo (solar reflectance). This sum (Q_{LW}) includes power transmitted from

- ceiling to left wall,
- ceiling to left wall to ground to left wall,
- ceiling to left wall to right wall to left wall,
- ceiling to ground to left wall,
- ceiling to ground to right wall to left wall,
- ceiling to right wall to left wall, and
- ceiling to right wall to ground to left wall.

Note that multipliers a, b, and c depend only on canyon surface albedos and canyon view factors, and that the view factors depend only on canyon aspect ratio R.

The cumulative irradiance on the left wall is

$$I_{\mathrm{LW}} = \frac{Q_{\mathrm{LW}}}{A_{\mathrm{LW}}} = Q''_{\mathrm{LW}} = a \times Q''_{\mathrm{i,LW}} + b \times Q''_{\mathrm{i,RW}} + c \times Q''_{\mathrm{i,G}}, \tag{A-28}$$

where double prime means normalized to left wall area $A_{\mathrm{LW}} = H \times L$. Starting with the first term of I_{LW} (left wall contribution), the left wall's initial global power $Q_{\mathrm{i,LW}}$ is the sum of its beam component $Q_{\text{i,LW,B}}$ and its diffuse component $Q_{\text{i,LW,D}}$. Recall that $Q_{\text{i,LW,B}} = Q_{\text{SFW,B}} = I_{\text{BH}} \times J \times L$ if $\cos \gamma_{\text{LW}} > 0$, or zero otherwise. Hence

$$Q''_{\text{i,LW,B}} = I_{\text{BH}} \times (J/H) \text{ if } \cos \gamma_{\text{LW}} > 0, \text{ or } 0 \text{ otherwise.} \tag{A-29}$$

Since $J = \min(H \times \tan \theta_{\text{z}} \times \cos \gamma_{\text{SFW}}, W)$,

$$J/H = \min(\tan \theta_{\text{z}} \times \cos \gamma_{\text{SFW}}, 1/R). \tag{A-30}$$

Note that J/H can be fully predicted from θ_{z}, γ_{LW}, and R.

Since $Q_{\text{i,LW,D}} = Q_{\text{C,D}} \times F_{\text{C}\to\text{LW}}$ and $Q_{\text{C,D}} = I_{\text{DH}} \times W \times L$,

$$Q''_{\text{i,LW,D}} = I_{\text{DH}} \times W \times L \times F_{\text{C}\to\text{LW}}/(H \times L) = I_{\text{DH}} \times F_{\text{C}\to\text{LW}}/R. \tag{A-31}$$

Summing beam and diffuse components,

$$\begin{gathered} Q''_{\text{i,LW}} = [I_{\text{BH}} \times (J/H) + I_{\text{DH}} \times F_{\text{C}\to\text{LW}}/R] \text{ if } \cos \gamma_{\text{LW}} > 0, \\ \text{or } (I_{\text{DH}} \times F_{\text{C}\to\text{LW}}/R) \text{ otherwise.} \end{gathered} \tag{A-32}$$

The derivation of the second term of I_{LW} (right wall contribution) is analogous to that of the first term (left wall contribution), yielding

$$\begin{gathered} Q''_{\text{i,RW}} = [I_{\text{BH}} \times (J/H) + I_{\text{DH}} \times F_{\text{C}\to\text{RW}}/R] \text{ if } \cos \gamma_{\text{RW}} > 0, \\ \text{or } (I_{\text{DH}} \times F_{\text{C}\to\text{RW}}/R) \text{ otherwise.} \end{gathered} \tag{A-33}$$

In the third term of I_{LW} (ground contribution), the ground's initial global power $Q_{\text{i,G}}$ is the sum of its initial beam power $Q_{\text{i,G,B}} = I_{\text{BH}} \times (W - J) \times L$ and its initial diffuse power $Q_{\text{i,G,D}} = Q_{\text{C,D}} \times F_{\text{C}\to\text{G}}$. Thus

$$\begin{aligned} Q''_{\text{i,G,B}} &= I_{\text{BH}} \times (W - J)/H = I_{\text{BH}} \times [(W/H) - (J/H)] \\ &= I_{\text{BH}} \times [(1/R) - (J/H)] \end{aligned} \tag{A-34}$$

and

$$Q''_{\text{i,G,D}} = (I_{\text{DH}} \times W \times L \times F_{\text{C}\to\text{G}})/(H \times L) = (I_{\text{DH}} \times F_{\text{C}\to\text{G}})/R. \tag{A-35}$$

Summing beam and diffuse contributions,

$$Q''_{\text{i,G}} = I_{\text{BH}} \times [(1/R) - (J/H)] + (I_{\text{DH}} \times F_{\text{C}\to\text{G}})/R. \tag{A-36}$$

Thus, the cumulative global irradiance on the left wall after no more than two reflections from canyon surfaces, I_{LW}, is computed from Eqs. (A-28), (A-32), (A-33), and (A-36), with coefficients a, b, and c from Eqs. (A-25) - (A-27); normalized shadow length J/H from Eq. (A-30); and assorted view factors from Eqs. (A-12), (A-13), (A-18), (A-19), (A-21), and (A-23). Each term in I_{LW} can be predicted from I_{BH}, I_{DH}, θ_{z}, γ_{LW}, γ_{RW}, and/or R.

Note that the sun-facing wall is that for which $\cos \gamma > 0$. If neither wall faces the sun, then $J/H = 0$.

ESM Appendix B: SAF tables and figures for scenarios 2 – 4

ESM Table B-1. Annual mean, minimum, maximum, and range (maximum – minimum) values of monthly SAF for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) with a cool neighboring wall (ρ=0.60). Results shown by climate for aspect ratios of (a) R=0.2, (b) R=1, (c) R=2, and (d) R=10.

(a) Aspect ratio R=0.2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.98	0.94	1.05	0.11	0.96	0.92	0.98	0.05	0.95	0.94	0.97	0.02	0.95	0.87	0.97	0.10
2A (Houston, TX)	0.99	0.93	1.05	0.12	0.94	0.90	0.97	0.07	0.95	0.94	0.96	0.03	0.94	0.89	0.97	0.08
2B (Phoenix, AZ)	1.03	0.89	1.18	0.29	0.95	0.90	0.99	0.09	0.96	0.96	0.97	0.01	0.95	0.92	0.98	0.06
3A (Memphis, TN)	1.01	0.95	1.10	0.14	0.95	0.88	0.97	0.09	0.96	0.95	0.97	0.02	0.94	0.88	0.97	0.10
3B (El Paso, TX)	1.04	0.95	1.15	0.20	0.97	0.91	0.99	0.08	0.97	0.96	0.98	0.02	0.97	0.94	0.98	0.04
BU (Burbank, CA)	1.02	0.96	1.13	0.17	0.96	0.92	0.98	0.06	0.96	0.96	0.97	0.01	0.96	0.93	0.98	0.05
FR (Fresno, CA)	1.01	0.96	1.06	0.09	0.96	0.93	0.98	0.05	0.96	0.96	0.97	0.01	0.96	0.94	0.98	0.04
3C (San Francisco, CA)	1.01	0.92	1.11	0.19	0.96	0.91	0.98	0.07	0.96	0.95	0.97	0.02	0.95	0.92	0.97	0.05
4A (Baltimore, MD)	1.01	0.92	1.10	0.19	0.93	0.77	0.97	0.20	0.95	0.91	0.97	0.06	0.94	0.86	0.97	0.10
4B (Albuquerque, NM)	1.05	0.94	1.25	0.32	0.95	0.90	0.99	0.08	0.96	0.95	0.97	0.02	0.95	0.92	0.99	0.07
4C (Seattle, WA)	1.00	0.95	1.05	0.10	0.94	0.88	0.97	0.08	0.95	0.92	0.97	0.05	0.94	0.85	0.97	0.12
5A (Chicago, IL)	1.00	0.95	1.08	0.14	0.94	0.89	0.97	0.08	0.95	0.93	0.96	0.04	0.94	0.87	0.97	0.10
5B (Boise, ID)	1.03	0.96	1.12	0.16	0.94	0.89	0.98	0.08	0.96	0.93	0.97	0.04	0.95	0.89	0.99	0.10
6A (Burlington, VT)	0.99	0.90	1.07	0.16	0.93	0.85	0.97	0.12	0.95	0.91	0.97	0.05	0.93	0.88	0.96	0.09
6B (Helena, MT)	1.03	0.96	1.15	0.19	0.94	0.89	0.97	0.08	0.96	0.92	0.97	0.05	0.93	0.82	0.98	0.16
7 (Duluth, MN)	1.01	0.91	1.10	0.19	0.94	0.86	0.98	0.12	0.95	0.92	0.97	0.05	0.93	0.87	0.97	0.10
8 (Fairbanks, AK)	0.98	0.81	1.13	0.32	0.79	0.57	0.95	0.39	0.80	0.25	0.97	0.72	0.96	0.73	1.00	0.28
U.S. (excluding CZ 8)	1.01	0.89	1.25	0.36	0.95	0.77	0.99	0.22	0.96	0.91	0.98	0.06	0.95	0.82	0.99	0.17

ESM Table B-1 (continued)

(b) Aspect ratio R=1

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.86	0.71	1.06	0.35	0.72	0.68	0.76	0.08	0.76	0.70	0.83	0.13	0.73	0.66	0.76	0.11
2A (Houston, TX)	0.87	0.71	1.04	0.33	0.72	0.66	0.75	0.09	0.75	0.62	0.83	0.21	0.71	0.65	0.76	0.11
2B (Phoenix, AZ)	1.02	0.70	1.29	0.59	0.70	0.64	0.75	0.11	0.77	0.55	0.87	0.31	0.71	0.64	0.76	0.12
3A (Memphis, TN)	0.91	0.75	1.08	0.33	0.71	0.65	0.76	0.12	0.74	0.53	0.84	0.31	0.70	0.63	0.77	0.14
3B (El Paso, TX)	1.02	0.76	1.31	0.55	0.73	0.68	0.78	0.10	0.77	0.58	0.86	0.28	0.73	0.67	0.79	0.13
BU (Burbank, CA)	0.96	0.76	1.18	0.41	0.73	0.67	0.79	0.12	0.76	0.55	0.85	0.31	0.73	0.67	0.79	0.12
FR (Fresno, CA)	0.92	0.78	1.12	0.34	0.72	0.67	0.76	0.10	0.76	0.53	0.87	0.34	0.73	0.68	0.77	0.09
3C (San Francisco, CA)	0.92	0.75	1.05	0.29	0.73	0.64	0.80	0.16	0.74	0.49	0.86	0.37	0.72	0.66	0.76	0.09
4A (Baltimore, MD)	0.91	0.73	1.06	0.33	0.69	0.53	0.74	0.21	0.71	0.46	0.84	0.38	0.69	0.61	0.76	0.15
4B (Albuquerque, NM)	1.05	0.77	1.37	0.60	0.70	0.63	0.75	0.12	0.76	0.52	0.87	0.35	0.72	0.64	0.81	0.16
4C (Seattle, WA)	0.85	0.78	0.97	0.20	0.69	0.63	0.75	0.13	0.68	0.40	0.84	0.44	0.68	0.58	0.75	0.17
5A (Chicago, IL)	0.87	0.75	0.98	0.23	0.69	0.60	0.74	0.14	0.70	0.44	0.84	0.40	0.70	0.61	0.75	0.15
5B (Boise, ID)	0.95	0.79	1.19	0.40	0.68	0.59	0.74	0.14	0.71	0.41	0.88	0.47	0.69	0.61	0.76	0.16
6A (Burlington, VT)	0.85	0.71	0.95	0.24	0.68	0.59	0.73	0.14	0.69	0.41	0.83	0.42	0.68	0.60	0.73	0.13
6B (Helena, MT)	0.94	0.79	1.07	0.28	0.67	0.58	0.73	0.15	0.68	0.35	0.85	0.50	0.66	0.53	0.75	0.22
7 (Duluth, MN)	0.88	0.76	1.00	0.24	0.67	0.58	0.74	0.16	0.67	0.37	0.84	0.47	0.66	0.59	0.72	0.13
8 (Fairbanks, AK)	0.79	0.61	0.96	0.35	0.46	0.28	0.65	0.37	0.50	0.11	0.84	0.73	0.69	0.42	0.77	0.35
U.S. (excluding CZ 8)	**0.92**	**0.70**	**1.37**	**0.67**	**0.70**	**0.53**	**0.80**	**0.27**	**0.73**	**0.35**	**0.88**	**0.53**	**0.70**	**0.53**	**0.81**	**0.28**

ESM Table B-1 (continued)

(c) Aspect ratio R=2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.65	0.52	0.77	0.25	0.51	0.47	0.54	0.06	0.54	0.39	0.67	0.28	0.52	0.47	0.55	0.09
2A (Houston, TX)	0.66	0.53	0.79	0.26	0.51	0.46	0.53	0.07	0.53	0.35	0.68	0.33	0.50	0.45	0.54	0.10
2B (Phoenix, AZ)	0.80	0.56	0.94	0.38	0.49	0.44	0.53	0.09	0.55	0.30	0.75	0.45	0.50	0.44	0.55	0.11
3A (Memphis, TN)	0.69	0.56	0.77	0.21	0.50	0.45	0.54	0.10	0.52	0.29	0.69	0.40	0.49	0.43	0.55	0.12
3B (El Paso, TX)	0.79	0.58	0.95	0.37	0.51	0.47	0.56	0.09	0.56	0.32	0.73	0.41	0.52	0.46	0.57	0.11
BU (Burbank, CA)	0.75	0.60	0.85	0.25	0.51	0.46	0.57	0.11	0.55	0.30	0.73	0.43	0.52	0.46	0.56	0.11
FR (Fresno, CA)	0.72	0.60	0.93	0.33	0.51	0.46	0.54	0.08	0.55	0.31	0.76	0.45	0.51	0.47	0.55	0.08
3C (San Francisco, CA)	0.71	0.60	0.87	0.27	0.52	0.44	0.58	0.14	0.53	0.28	0.72	0.44	0.50	0.45	0.54	0.08
4A (Baltimore, MD)	0.69	0.57	0.77	0.19	0.48	0.36	0.53	0.17	0.50	0.26	0.67	0.41	0.49	0.41	0.54	0.13
4B (Albuquerque, NM)	0.81	0.60	1.00	0.40	0.49	0.43	0.53	0.10	0.54	0.28	0.73	0.45	0.51	0.44	0.59	0.15
4C (Seattle, WA)	0.64	0.57	0.72	0.15	0.48	0.43	0.55	0.12	0.47	0.24	0.71	0.47	0.47	0.39	0.54	0.14
5A (Chicago, IL)	0.65	0.59	0.71	0.13	0.48	0.41	0.52	0.12	0.49	0.25	0.67	0.41	0.49	0.41	0.54	0.12
5B (Boise, ID)	0.74	0.61	0.93	0.32	0.47	0.40	0.52	0.11	0.51	0.23	0.74	0.51	0.48	0.42	0.54	0.13
6A (Burlington, VT)	0.64	0.55	0.70	0.14	0.47	0.40	0.51	0.11	0.48	0.24	0.67	0.43	0.47	0.41	0.52	0.10
6B (Helena, MT)	0.71	0.64	0.81	0.17	0.46	0.39	0.51	0.12	0.47	0.20	0.75	0.55	0.45	0.35	0.53	0.18
7 (Duluth, MN)	0.66	0.60	0.72	0.12	0.47	0.39	0.52	0.13	0.47	0.22	0.70	0.48	0.46	0.40	0.51	0.11
8 (Fairbanks, AK)	0.57	0.45	0.69	0.24	0.31	0.18	0.44	0.26	0.31	0.07	0.57	0.50	0.48	0.28	0.54	0.26
U.S. (excluding CZ 8)	**0.71**	**0.52**	**1.00**	**0.47**	**0.49**	**0.36**	**0.58**	**0.22**	**0.52**	**0.20**	**0.76**	**0.56**	**0.49**	**0.35**	**0.59**	**0.24**

ESM Table B-1 (continued)

(d) Aspect ratio R=10

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.20	0.17	0.22	0.05	0.14	0.13	0.15	0.02	0.16	0.09	0.22	0.13	0.14	0.13	0.16	0.03
2A (Houston, TX)	0.20	0.18	0.22	0.04	0.14	0.12	0.15	0.02	0.15	0.08	0.22	0.14	0.14	0.12	0.15	0.03
2B (Phoenix, AZ)	0.25	0.21	0.27	0.05	0.13	0.12	0.15	0.02	0.16	0.07	0.30	0.23	0.14	0.12	0.15	0.03
3A (Memphis, TN)	0.21	0.20	0.22	0.02	0.14	0.12	0.16	0.03	0.15	0.07	0.23	0.16	0.14	0.12	0.16	0.04
3B (El Paso, TX)	0.25	0.22	0.27	0.05	0.14	0.13	0.16	0.03	0.17	0.07	0.30	0.23	0.15	0.13	0.17	0.04
BU (Burbank, CA)	0.23	0.20	0.25	0.05	0.15	0.13	0.17	0.04	0.16	0.07	0.27	0.20	0.14	0.12	0.16	0.04
FR (Fresno, CA)	0.22	0.17	0.27	0.10	0.14	0.13	0.16	0.03	0.16	0.07	0.28	0.20	0.14	0.13	0.16	0.03
3C (San Francisco, CA)	0.21	0.19	0.25	0.06	0.14	0.12	0.16	0.04	0.15	0.06	0.25	0.18	0.14	0.12	0.15	0.03
4A (Baltimore, MD)	0.20	0.19	0.22	0.03	0.13	0.10	0.15	0.05	0.13	0.06	0.22	0.16	0.14	0.11	0.16	0.04
4B (Albuquerque, NM)	0.25	0.22	0.28	0.06	0.14	0.12	0.15	0.03	0.16	0.06	0.29	0.23	0.14	0.12	0.17	0.05
4C (Seattle, WA)	0.18	0.16	0.21	0.05	0.13	0.12	0.15	0.04	0.12	0.06	0.19	0.13	0.13	0.11	0.16	0.05
5A (Chicago, IL)	0.19	0.17	0.20	0.03	0.13	0.11	0.15	0.04	0.13	0.06	0.21	0.15	0.14	0.11	0.15	0.04
5B (Boise, ID)	0.22	0.17	0.27	0.09	0.13	0.11	0.15	0.04	0.13	0.05	0.23	0.17	0.13	0.11	0.15	0.05
6A (Burlington, VT)	0.18	0.16	0.20	0.04	0.13	0.11	0.15	0.03	0.12	0.06	0.19	0.14	0.13	0.11	0.15	0.04
6B (Helena, MT)	0.21	0.19	0.23	0.04	0.12	0.11	0.13	0.03	0.12	0.05	0.21	0.16	0.12	0.10	0.14	0.04
7 (Duluth, MN)	0.19	0.17	0.21	0.04	0.13	0.11	0.14	0.04	0.12	0.05	0.19	0.14	0.13	0.11	0.14	0.04
8 (Fairbanks, AK)	0.16	0.13	0.20	0.07	0.08	0.05	0.12	0.07	0.08	0.02	0.14	0.12	0.13	0.08	0.15	0.07
U.S. (excluding CZ 8)	**0.21**	**0.16**	**0.28**	**0.12**	**0.14**	**0.10**	**0.17**	**0.07**	**0.14**	**0.05**	**0.30**	**0.25**	**0.14**	**0.10**	**0.17**	**0.08**

ESM Table B-2. Same as ESM Table B-1, but for cool central wall (ρ=0.60) with a conventional neighboring wall (ρ=0.25).

(a) Aspect ratio R=0.2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.92	0.91	0.93	0.02	0.93	0.89	0.94	0.05	0.94	0.91	0.96	0.05	0.92	0.84	0.94	0.10
2A (Houston, TX)	0.92	0.89	0.93	0.03	0.91	0.87	0.94	0.07	0.94	0.91	0.96	0.04	0.91	0.86	0.94	0.07
2B (Phoenix, AZ)	0.92	0.86	0.95	0.09	0.92	0.87	0.95	0.08	0.95	0.93	0.97	0.04	0.92	0.89	0.95	0.06
3A (Memphis, TN)	0.92	0.91	0.94	0.03	0.92	0.85	0.94	0.08	0.94	0.92	0.96	0.04	0.91	0.85	0.94	0.10
3B (El Paso, TX)	0.93	0.91	0.95	0.03	0.94	0.89	0.96	0.07	0.95	0.93	0.97	0.04	0.93	0.91	0.95	0.04
BU (Burbank, CA)	0.93	0.92	0.94	0.03	0.93	0.89	0.95	0.06	0.95	0.93	0.97	0.04	0.93	0.90	0.95	0.05
FR (Fresno, CA)	0.92	0.90	0.93	0.03	0.93	0.90	0.95	0.04	0.95	0.94	0.96	0.03	0.93	0.91	0.95	0.04
3C (San Francisco, CA)	0.92	0.88	0.94	0.06	0.93	0.88	0.94	0.07	0.95	0.93	0.96	0.03	0.93	0.89	0.94	0.05
4A (Baltimore, MD)	0.92	0.88	0.94	0.06	0.90	0.75	0.94	0.19	0.94	0.91	0.96	0.05	0.90	0.83	0.93	0.10
4B (Albuquerque, NM)	0.93	0.88	0.97	0.09	0.92	0.87	0.96	0.08	0.95	0.94	0.97	0.04	0.92	0.89	0.95	0.06
4C (Seattle, WA)	0.91	0.90	0.93	0.03	0.91	0.86	0.94	0.08	0.94	0.91	0.96	0.05	0.91	0.82	0.94	0.12
5A (Chicago, IL)	0.92	0.91	0.93	0.02	0.91	0.86	0.94	0.08	0.94	0.92	0.96	0.03	0.91	0.84	0.94	0.10
5B (Boise, ID)	0.92	0.90	0.94	0.03	0.91	0.86	0.95	0.08	0.95	0.93	0.97	0.04	0.92	0.86	0.95	0.09
6A (Burlington, VT)	0.91	0.87	0.93	0.06	0.90	0.82	0.94	0.12	0.94	0.91	0.96	0.05	0.90	0.85	0.93	0.08
6B (Helena, MT)	0.92	0.89	0.94	0.06	0.91	0.86	0.94	0.08	0.95	0.91	0.97	0.05	0.90	0.80	0.95	0.15
7 (Duluth, MN)	0.91	0.86	0.93	0.07	0.91	0.83	0.94	0.11	0.94	0.91	0.96	0.05	0.90	0.84	0.94	0.10
8 (Fairbanks, AK)	0.88	0.78	0.94	0.16	0.77	0.56	0.92	0.36	0.79	0.24	0.96	0.72	0.91	0.70	0.94	0.24
U.S. (excluding CZ 8)	**0.92**	**0.86**	**0.97**	**0.11**	**0.92**	**0.75**	**0.96**	**0.21**	**0.95**	**0.91**	**0.97**	**0.07**	**0.92**	**0.80**	**0.95**	**0.16**

ESM Table B-2 (continued)

(b) Aspect ratio R=1

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.66	0.62	0.70	0.07	0.64	0.60	0.67	0.07	0.72	0.62	0.81	0.19	0.64	0.58	0.67	0.09
2A (Houston, TX)	0.66	0.62	0.69	0.07	0.63	0.58	0.67	0.09	0.71	0.60	0.82	0.21	0.63	0.58	0.67	0.09
2B (Phoenix, AZ)	0.69	0.62	0.76	0.14	0.63	0.57	0.66	0.09	0.74	0.55	0.85	0.30	0.63	0.58	0.68	0.10
3A (Memphis, TN)	0.67	0.64	0.70	0.06	0.63	0.57	0.68	0.10	0.70	0.51	0.81	0.30	0.62	0.56	0.68	0.12
3B (El Paso, TX)	0.70	0.66	0.76	0.10	0.65	0.61	0.70	0.09	0.74	0.58	0.84	0.26	0.65	0.59	0.70	0.11
BU (Burbank, CA)	0.68	0.64	0.73	0.08	0.64	0.60	0.70	0.10	0.73	0.54	0.83	0.30	0.65	0.59	0.70	0.11
FR (Fresno, CA)	0.67	0.64	0.71	0.07	0.64	0.59	0.68	0.09	0.73	0.52	0.86	0.34	0.64	0.61	0.68	0.07
3C (San Francisco, CA)	0.67	0.63	0.70	0.07	0.64	0.57	0.69	0.12	0.71	0.48	0.85	0.36	0.64	0.59	0.68	0.09
4A (Baltimore, MD)	0.66	0.62	0.70	0.08	0.61	0.47	0.66	0.19	0.68	0.45	0.82	0.37	0.61	0.55	0.67	0.12
4B (Albuquerque, NM)	0.70	0.63	0.78	0.15	0.62	0.56	0.68	0.12	0.73	0.52	0.85	0.33	0.63	0.57	0.70	0.13
4C (Seattle, WA)	0.65	0.63	0.68	0.05	0.61	0.56	0.67	0.11	0.65	0.38	0.81	0.43	0.60	0.52	0.66	0.14
5A (Chicago, IL)	0.65	0.63	0.68	0.04	0.61	0.53	0.65	0.12	0.66	0.42	0.82	0.39	0.62	0.54	0.66	0.12
5B (Boise, ID)	0.68	0.65	0.73	0.08	0.60	0.52	0.66	0.13	0.69	0.40	0.87	0.47	0.61	0.54	0.68	0.14
6A (Burlington, VT)	0.64	0.60	0.67	0.07	0.60	0.53	0.65	0.12	0.66	0.40	0.80	0.40	0.60	0.54	0.65	0.11
6B (Helena, MT)	0.67	0.64	0.70	0.06	0.60	0.51	0.66	0.14	0.66	0.34	0.84	0.49	0.59	0.47	0.66	0.18
7 (Duluth, MN)	0.65	0.60	0.68	0.08	0.59	0.51	0.65	0.13	0.65	0.36	0.81	0.45	0.59	0.53	0.65	0.12
8 (Fairbanks, AK)	0.61	0.49	0.66	0.17	0.42	0.26	0.57	0.32	0.48	0.10	0.81	0.71	0.59	0.37	0.65	0.28
U.S. (excluding CZ 8)	**0.67**	**0.60**	**0.78**	**0.18**	**0.62**	**0.47**	**0.70**	**0.22**	**0.70**	**0.34**	**0.87**	**0.53**	**0.62**	**0.47**	**0.70**	**0.23**

ESM Table B-2 (continued)

(c) Aspect ratio R=2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.46	0.44	0.49	0.05	0.44	0.40	0.46	0.06	0.50	0.38	0.65	0.27	0.44	0.40	0.47	0.07
2A (Houston, TX)	0.46	0.44	0.49	0.05	0.43	0.39	0.46	0.07	0.49	0.33	0.65	0.32	0.43	0.38	0.46	0.07
2B (Phoenix, AZ)	0.50	0.45	0.53	0.08	0.42	0.38	0.45	0.07	0.52	0.29	0.72	0.43	0.42	0.37	0.47	0.09
3A (Memphis, TN)	0.47	0.45	0.49	0.03	0.43	0.38	0.46	0.08	0.49	0.28	0.65	0.37	0.42	0.37	0.47	0.10
3B (El Paso, TX)	0.51	0.47	0.53	0.06	0.44	0.40	0.48	0.08	0.52	0.31	0.70	0.39	0.44	0.39	0.48	0.09
BU (Burbank, CA)	0.49	0.46	0.51	0.05	0.43	0.40	0.48	0.08	0.52	0.29	0.70	0.41	0.44	0.39	0.48	0.09
FR (Fresno, CA)	0.48	0.44	0.53	0.09	0.43	0.39	0.46	0.07	0.52	0.29	0.73	0.44	0.43	0.40	0.46	0.06
3C (San Francisco, CA)	0.47	0.45	0.51	0.06	0.43	0.37	0.48	0.11	0.50	0.26	0.69	0.42	0.43	0.39	0.46	0.07
4A (Baltimore, MD)	0.47	0.44	0.48	0.05	0.41	0.31	0.45	0.14	0.47	0.25	0.64	0.39	0.41	0.36	0.46	0.10
4B (Albuquerque, NM)	0.51	0.46	0.55	0.09	0.42	0.37	0.46	0.09	0.52	0.27	0.71	0.43	0.43	0.37	0.49	0.12
4C (Seattle, WA)	0.45	0.43	0.47	0.04	0.41	0.37	0.46	0.09	0.44	0.22	0.67	0.45	0.40	0.34	0.45	0.11
5A (Chicago, IL)	0.46	0.45	0.47	0.02	0.41	0.35	0.44	0.10	0.46	0.24	0.62	0.38	0.41	0.35	0.45	0.10
5B (Boise, ID)	0.48	0.44	0.53	0.09	0.40	0.34	0.44	0.10	0.48	0.22	0.72	0.50	0.41	0.35	0.46	0.11
6A (Burlington, VT)	0.45	0.43	0.47	0.04	0.40	0.34	0.43	0.09	0.45	0.22	0.62	0.40	0.40	0.35	0.44	0.09
6B (Helena, MT)	0.47	0.45	0.50	0.04	0.39	0.33	0.44	0.11	0.45	0.19	0.71	0.52	0.38	0.30	0.44	0.14
7 (Duluth, MN)	0.46	0.44	0.48	0.04	0.40	0.33	0.43	0.10	0.44	0.20	0.65	0.45	0.39	0.34	0.43	0.09
8 (Fairbanks, AK)	0.41	0.33	0.46	0.12	0.27	0.16	0.37	0.21	0.29	0.06	0.53	0.46	0.39	0.24	0.44	0.20
U.S. (excluding CZ 8)	**0.47**	**0.43**	**0.55**	**0.12**	**0.42**	**0.31**	**0.48**	**0.18**	**0.49**	**0.19**	**0.73**	**0.54**	**0.42**	**0.30**	**0.49**	**0.19**

ESM Table B-2 (continued)

(d) Aspect ratio R=10

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.13	0.12	0.14	0.02	0.11	0.10	0.12	0.02	0.14	0.09	0.20	0.12	0.12	0.10	0.12	0.02
2A (Houston, TX)	0.13	0.13	0.14	0.01	0.11	0.10	0.12	0.02	0.14	0.08	0.19	0.12	0.11	0.10	0.12	0.02
2B (Phoenix, AZ)	0.15	0.14	0.15	0.01	0.11	0.10	0.12	0.02	0.15	0.06	0.26	0.20	0.11	0.09	0.12	0.03
3A (Memphis, TN)	0.13	0.13	0.14	0.01	0.11	0.10	0.13	0.03	0.13	0.06	0.21	0.14	0.11	0.10	0.13	0.03
3B (El Paso, TX)	0.15	0.14	0.17	0.03	0.12	0.10	0.13	0.03	0.16	0.07	0.26	0.20	0.12	0.10	0.14	0.03
BU (Burbank, CA)	0.14	0.13	0.15	0.02	0.12	0.10	0.14	0.03	0.15	0.06	0.24	0.18	0.12	0.10	0.13	0.03
FR (Fresno, CA)	0.14	0.12	0.16	0.04	0.12	0.10	0.13	0.02	0.15	0.07	0.25	0.18	0.12	0.10	0.13	0.02
3C (San Francisco, CA)	0.13	0.12	0.14	0.02	0.12	0.10	0.13	0.03	0.14	0.06	0.23	0.17	0.11	0.10	0.13	0.02
4A (Baltimore, MD)	0.13	0.13	0.14	0.01	0.11	0.08	0.12	0.04	0.12	0.06	0.20	0.14	0.11	0.09	0.13	0.03
4B (Albuquerque, NM)	0.15	0.14	0.15	0.02	0.11	0.09	0.13	0.03	0.15	0.06	0.26	0.20	0.12	0.10	0.14	0.04
4C (Seattle, WA)	0.12	0.12	0.13	0.02	0.11	0.09	0.12	0.03	0.11	0.05	0.17	0.12	0.11	0.09	0.12	0.03
5A (Chicago, IL)	0.13	0.12	0.13	0.01	0.11	0.09	0.12	0.03	0.12	0.05	0.19	0.13	0.11	0.09	0.12	0.03
5B (Boise, ID)	0.13	0.12	0.15	0.03	0.10	0.09	0.12	0.03	0.12	0.05	0.21	0.16	0.10	0.09	0.12	0.04
6A (Burlington, VT)	0.12	0.12	0.13	0.01	0.11	0.09	0.12	0.03	0.11	0.05	0.17	0.12	0.10	0.09	0.12	0.03
6B (Helena, MT)	0.13	0.13	0.15	0.02	0.10	0.09	0.11	0.02	0.11	0.04	0.19	0.15	0.10	0.08	0.11	0.03
7 (Duluth, MN)	0.13	0.12	0.13	0.01	0.10	0.09	0.12	0.03	0.11	0.05	0.17	0.13	0.10	0.09	0.12	0.03
8 (Fairbanks, AK)	0.11	0.09	0.12	0.03	0.07	0.04	0.10	0.06	0.07	0.02	0.13	0.11	0.10	0.06	0.11	0.05
U.S. (excluding CZ 8)	**0.13**	**0.12**	**0.17**	**0.05**	**0.11**	**0.08**	**0.14**	**0.06**	**0.13**	**0.04**	**0.26**	**0.22**	**0.11**	**0.08**	**0.14**	**0.06**

ESM Table B-3. Same as Table B-1, but for cool central wall (ρ=0.60) with a cool neighboring wall (ρ=0.60).

(a) Aspect ratio R=0.2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.99	0.95	1.05	0.11	0.96	0.92	0.98	0.05	0.96	0.95	0.97	0.03	0.95	0.87	0.97	0.10
2A (Houston, TX)	0.99	0.93	1.05	0.12	0.95	0.90	0.97	0.07	0.96	0.94	0.97	0.03	0.95	0.89	0.97	0.08
2B (Phoenix, AZ)	1.03	0.89	1.18	0.29	0.95	0.90	0.99	0.09	0.97	0.96	0.98	0.02	0.96	0.92	0.98	0.06
3A (Memphis, TN)	1.01	0.96	1.10	0.14	0.96	0.89	0.97	0.09	0.96	0.95	0.97	0.02	0.95	0.88	0.98	0.10
3B (El Paso, TX)	1.04	0.96	1.15	0.20	0.98	0.92	1.00	0.08	0.97	0.96	0.98	0.02	0.97	0.94	0.98	0.04
BU (Burbank, CA)	1.03	0.96	1.13	0.17	0.96	0.92	0.98	0.06	0.97	0.96	0.97	0.02	0.97	0.93	0.99	0.05
FR (Fresno, CA)	1.01	0.97	1.06	0.09	0.96	0.94	0.98	0.05	0.97	0.96	0.98	0.01	0.96	0.94	0.98	0.04
3C (San Francisco, CA)	1.01	0.92	1.11	0.19	0.96	0.91	0.98	0.07	0.97	0.95	0.97	0.02	0.96	0.92	0.98	0.05
4A (Baltimore, MD)	1.01	0.92	1.11	0.19	0.93	0.77	0.97	0.20	0.96	0.92	0.97	0.06	0.94	0.87	0.97	0.10
4B (Albuquerque, NM)	1.06	0.94	1.26	0.32	0.95	0.91	0.99	0.08	0.97	0.96	0.98	0.02	0.96	0.92	0.99	0.07
4C (Seattle, WA)	1.00	0.95	1.06	0.10	0.95	0.89	0.97	0.08	0.96	0.92	0.97	0.05	0.94	0.85	0.97	0.12
5A (Chicago, IL)	1.00	0.95	1.09	0.14	0.94	0.89	0.97	0.08	0.96	0.93	0.97	0.04	0.95	0.87	0.98	0.10
5B (Boise, ID)	1.03	0.96	1.12	0.16	0.95	0.89	0.98	0.08	0.97	0.94	0.98	0.04	0.95	0.90	0.99	0.10
6A (Burlington, VT)	0.99	0.91	1.07	0.16	0.94	0.85	0.97	0.12	0.96	0.92	0.97	0.05	0.94	0.88	0.97	0.09
6B (Helena, MT)	1.04	0.96	1.15	0.19	0.95	0.89	0.97	0.08	0.96	0.92	0.98	0.05	0.94	0.83	0.99	0.16
7 (Duluth, MN)	1.01	0.91	1.11	0.19	0.94	0.86	0.98	0.12	0.96	0.92	0.97	0.05	0.93	0.87	0.97	0.10
8 (Fairbanks, AK)	0.99	0.82	1.13	0.32	0.79	0.57	0.96	0.39	0.81	0.25	0.97	0.73	0.96	0.73	1.01	0.28
U.S. (excluding CZ 8)	**1.02**	**0.89**	**1.26**	**0.36**	**0.95**	**0.77**	**1.00**	**0.22**	**0.96**	**0.92**	**0.98**	**0.06**	**0.95**	**0.83**	**0.99**	**0.17**

ESM Table B-3 (continued)

(b) Aspect ratio R=1

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.87	0.73	1.08	0.35	0.75	0.70	0.78	0.08	0.79	0.73	0.86	0.13	0.75	0.68	0.78	0.11
2A (Houston, TX)	0.89	0.73	1.06	0.32	0.74	0.68	0.77	0.09	0.78	0.64	0.86	0.22	0.73	0.67	0.78	0.11
2B (Phoenix, AZ)	1.03	0.72	1.31	0.59	0.73	0.66	0.77	0.12	0.79	0.57	0.90	0.33	0.73	0.66	0.79	0.12
3A (Memphis, TN)	0.93	0.76	1.09	0.33	0.74	0.67	0.79	0.12	0.76	0.55	0.87	0.32	0.72	0.65	0.79	0.14
3B (El Paso, TX)	1.04	0.78	1.33	0.55	0.75	0.70	0.81	0.10	0.80	0.61	0.89	0.28	0.75	0.69	0.82	0.13
BU (Burbank, CA)	0.98	0.78	1.19	0.41	0.75	0.69	0.82	0.12	0.78	0.57	0.89	0.32	0.76	0.69	0.81	0.12
FR (Fresno, CA)	0.94	0.80	1.14	0.34	0.74	0.69	0.79	0.10	0.79	0.55	0.90	0.35	0.75	0.70	0.79	0.09
3C (San Francisco, CA)	0.93	0.77	1.06	0.29	0.75	0.66	0.82	0.16	0.77	0.51	0.90	0.38	0.74	0.68	0.78	0.10
4A (Baltimore, MD)	0.93	0.75	1.08	0.33	0.71	0.55	0.77	0.22	0.74	0.48	0.87	0.39	0.71	0.63	0.78	0.15
4B (Albuquerque, NM)	1.06	0.79	1.39	0.60	0.72	0.65	0.77	0.12	0.78	0.54	0.90	0.36	0.74	0.66	0.83	0.17
4C (Seattle, WA)	0.87	0.80	0.99	0.19	0.71	0.65	0.78	0.13	0.70	0.41	0.87	0.45	0.70	0.60	0.78	0.18
5A (Chicago, IL)	0.89	0.77	0.99	0.23	0.71	0.62	0.76	0.14	0.72	0.45	0.87	0.42	0.72	0.62	0.78	0.15
5B (Boise, ID)	0.97	0.81	1.20	0.40	0.70	0.61	0.76	0.15	0.74	0.42	0.91	0.49	0.71	0.62	0.79	0.16
6A (Burlington, VT)	0.86	0.73	0.97	0.24	0.70	0.61	0.75	0.14	0.72	0.43	0.86	0.43	0.70	0.62	0.75	0.13
6B (Helena, MT)	0.95	0.81	1.09	0.28	0.69	0.60	0.75	0.16	0.71	0.37	0.89	0.52	0.68	0.55	0.77	0.22
7 (Duluth, MN)	0.90	0.77	1.01	0.24	0.69	0.60	0.76	0.16	0.70	0.39	0.87	0.48	0.68	0.61	0.75	0.14
8 (Fairbanks, AK)	0.81	0.63	0.98	0.35	0.48	0.29	0.67	0.38	0.52	0.12	0.87	0.76	0.71	0.43	0.79	0.36
U.S. (excluding CZ 8)	**0.94**	**0.72**	**1.39**	**0.66**	**0.72**	**0.55**	**0.82**	**0.27**	**0.75**	**0.37**	**0.91**	**0.55**	**0.72**	**0.55**	**0.83**	**0.28**

ESM Table B-3 (continued)

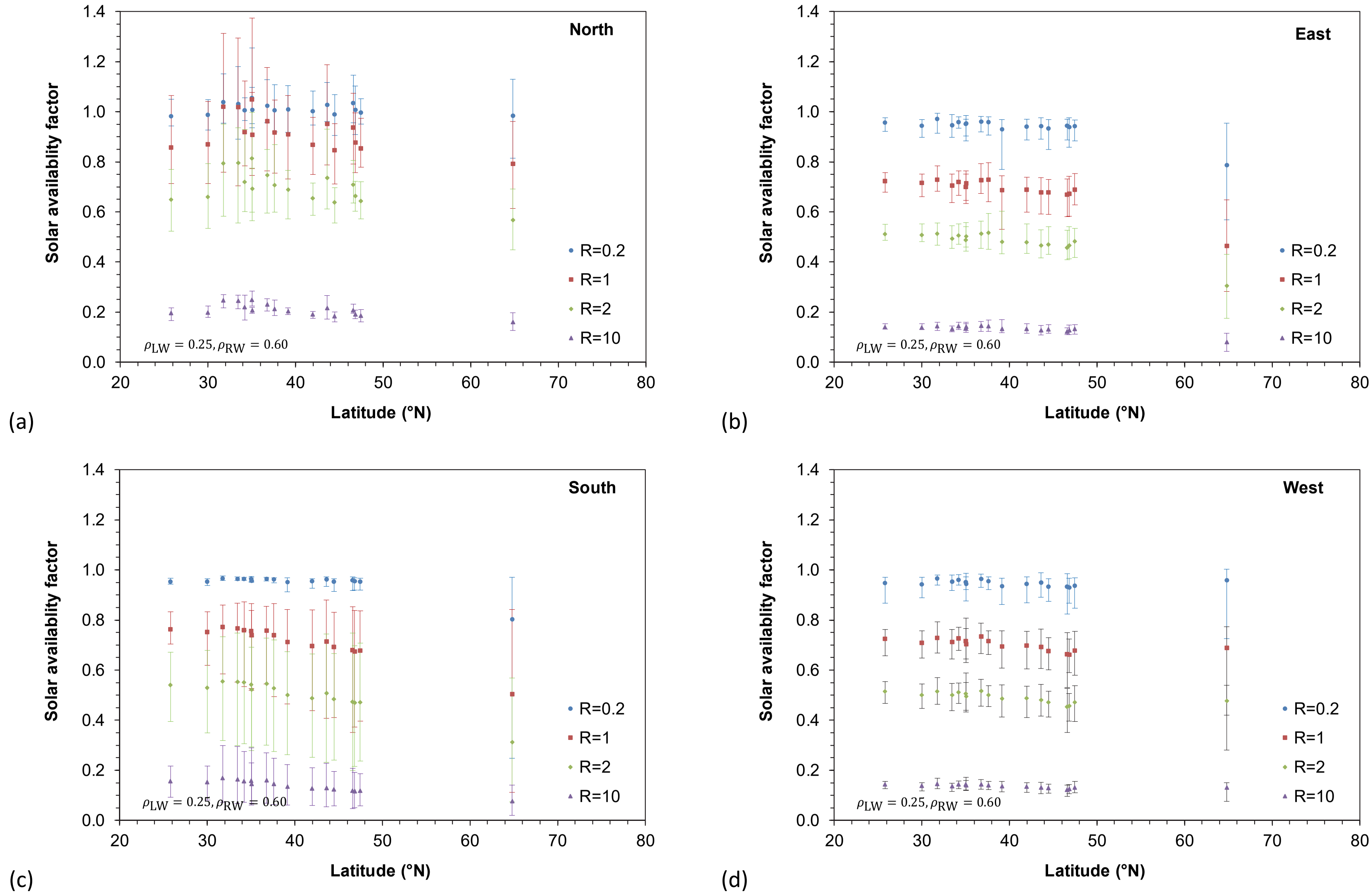
(c) Aspect ratio R=2

	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.67	0.55	0.79	0.24	0.54	0.50	0.57	0.07	0.58	0.42	0.72	0.30	0.54	0.49	0.58	0.09
2A (Houston, TX)	0.68	0.56	0.81	0.25	0.54	0.49	0.56	0.07	0.56	0.37	0.73	0.35	0.53	0.47	0.57	0.10
2B (Phoenix, AZ)	0.82	0.58	0.95	0.37	0.52	0.47	0.56	0.09	0.59	0.32	0.80	0.48	0.53	0.46	0.58	0.11
3A (Memphis, TN)	0.71	0.59	0.80	0.21	0.53	0.47	0.58	0.10	0.56	0.32	0.74	0.42	0.52	0.46	0.58	0.12
3B (El Paso, TX)	0.81	0.61	0.97	0.36	0.54	0.50	0.59	0.09	0.59	0.34	0.78	0.44	0.54	0.49	0.60	0.11
BU (Burbank, CA)	0.77	0.62	0.87	0.25	0.54	0.49	0.60	0.11	0.58	0.32	0.78	0.46	0.55	0.48	0.59	0.11
FR (Fresno, CA)	0.74	0.63	0.95	0.32	0.54	0.49	0.57	0.08	0.59	0.33	0.81	0.49	0.54	0.49	0.58	0.09
3C (San Francisco, CA)	0.73	0.62	0.89	0.26	0.55	0.46	0.61	0.15	0.57	0.30	0.77	0.48	0.53	0.48	0.57	0.09
4A (Baltimore, MD)	0.71	0.60	0.79	0.19	0.51	0.38	0.56	0.18	0.53	0.28	0.72	0.44	0.51	0.44	0.57	0.14
4B (Albuquerque, NM)	0.83	0.63	1.01	0.39	0.52	0.46	0.56	0.10	0.58	0.30	0.79	0.49	0.53	0.46	0.62	0.15
4C (Seattle, WA)	0.67	0.60	0.74	0.15	0.51	0.45	0.58	0.12	0.51	0.25	0.76	0.51	0.50	0.42	0.57	0.15
5A (Chicago, IL)	0.68	0.61	0.74	0.12	0.51	0.43	0.55	0.12	0.52	0.27	0.71	0.44	0.52	0.43	0.57	0.13
5B (Boise, ID)	0.76	0.64	0.95	0.31	0.49	0.43	0.55	0.12	0.54	0.25	0.80	0.55	0.51	0.44	0.57	0.13
6A (Burlington, VT)	0.66	0.58	0.72	0.14	0.50	0.42	0.54	0.12	0.52	0.26	0.71	0.46	0.50	0.44	0.55	0.11
6B (Helena, MT)	0.73	0.66	0.83	0.17	0.48	0.41	0.54	0.12	0.51	0.21	0.80	0.59	0.48	0.37	0.56	0.18
7 (Duluth, MN)	0.69	0.63	0.74	0.12	0.49	0.42	0.55	0.13	0.50	0.23	0.74	0.51	0.48	0.42	0.54	0.12
8 (Fairbanks, AK)	0.59	0.47	0.71	0.25	0.32	0.19	0.46	0.27	0.33	0.08	0.61	0.53	0.50	0.30	0.57	0.27
U.S. (excluding CZ 8)	**0.73**	**0.55**	**1.01**	**0.46**	**0.52**	**0.38**	**0.61**	**0.23**	**0.55**	**0.21**	**0.81**	**0.60**	**0.52**	**0.37**	**0.62**	**0.25**

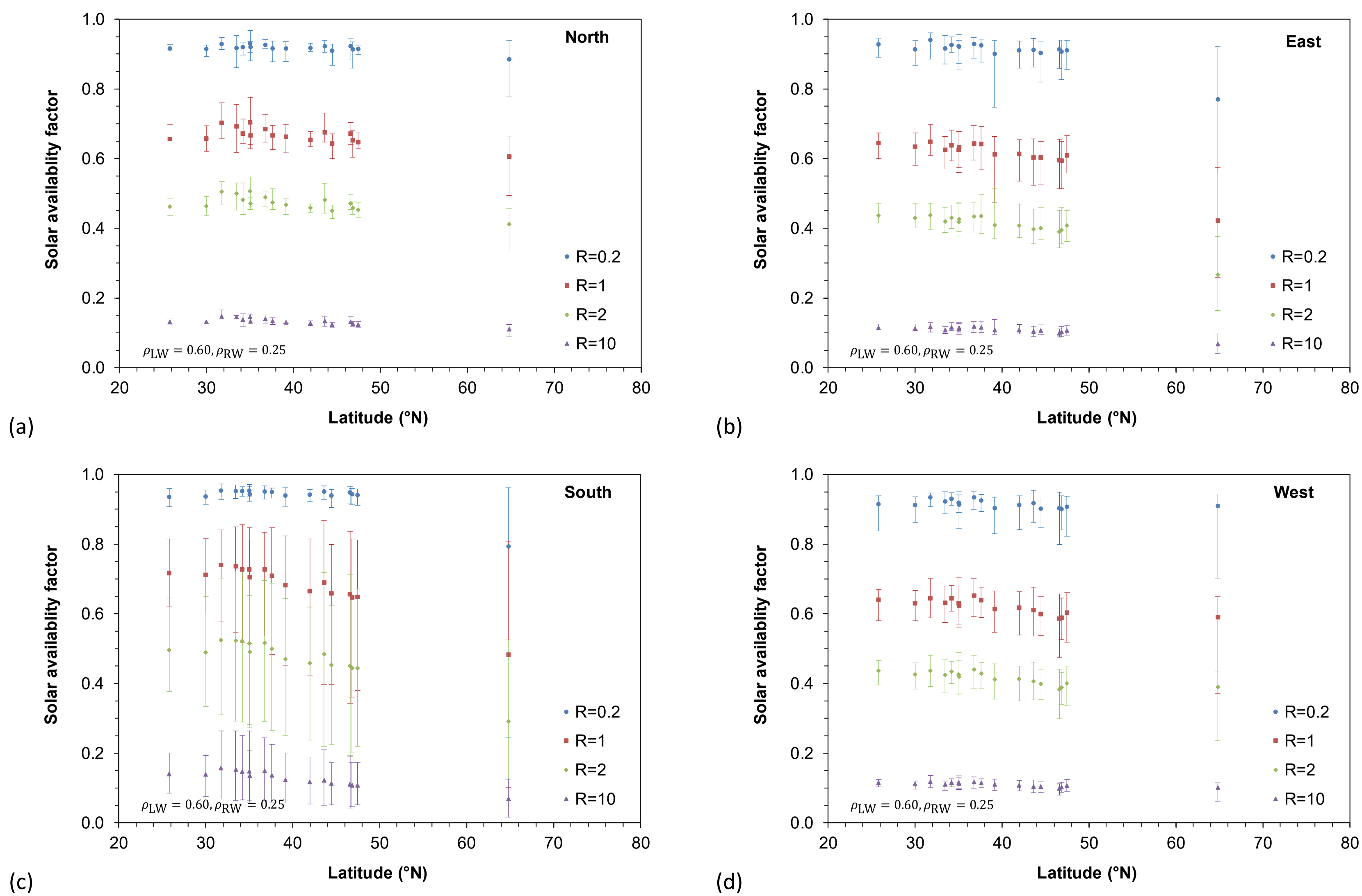
ESM Table B-3 (continued)

(d) Aspect ratio R=10

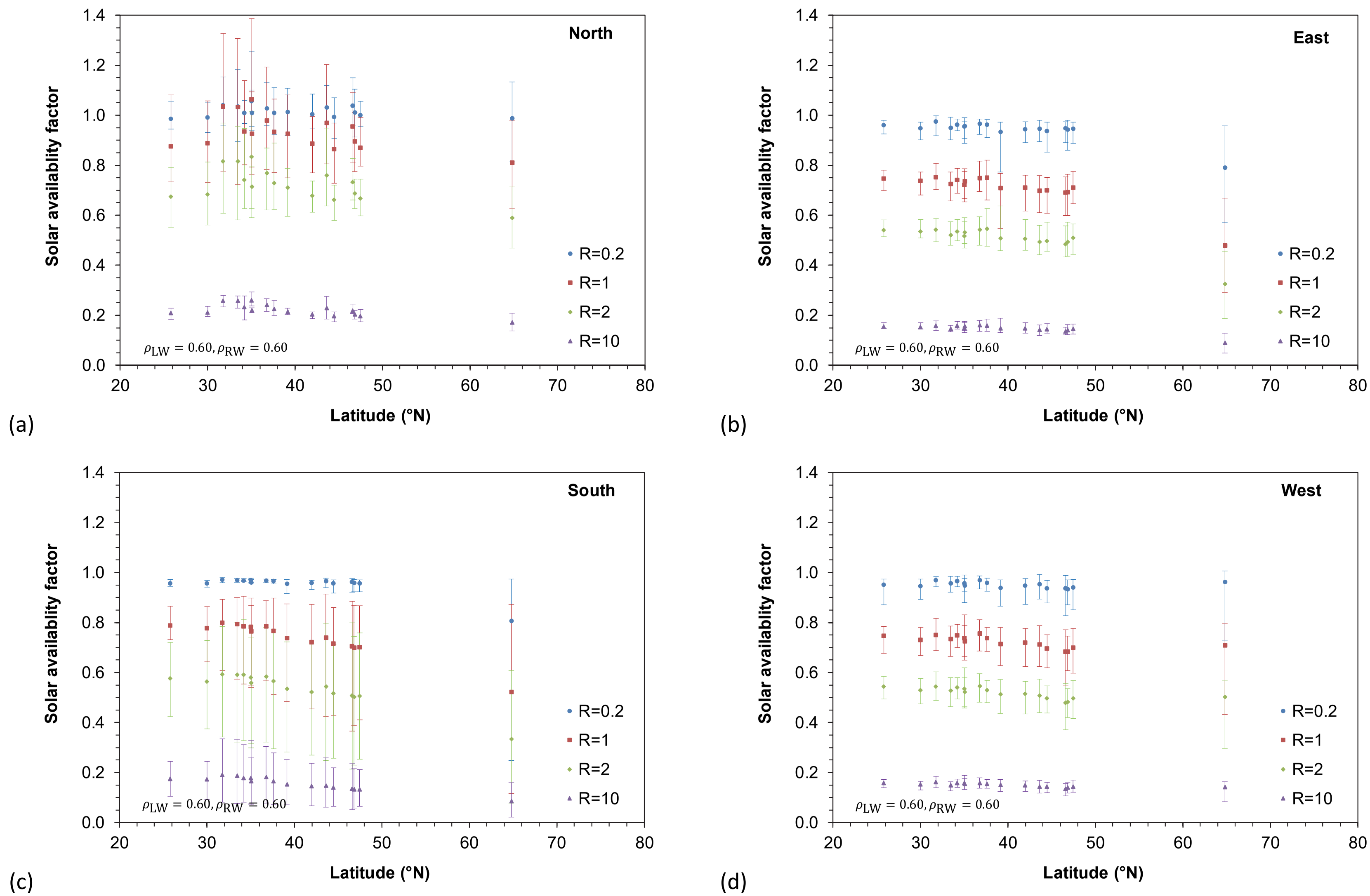
	N				E				S				W			
	mean	min	max	range	mean	min	max	range	mean	min	max	range	mean	min	max	range
1A (Miami, FL)	0.21	0.18	0.23	0.05	0.15	0.14	0.16	0.02	0.18	0.10	0.24	0.14	0.16	0.14	0.17	0.03
2A (Houston, TX)	0.21	0.20	0.24	0.04	0.15	0.14	0.16	0.03	0.17	0.09	0.24	0.15	0.15	0.13	0.17	0.03
2B (Phoenix, AZ)	0.26	0.23	0.28	0.05	0.15	0.13	0.16	0.03	0.19	0.08	0.33	0.26	0.15	0.13	0.16	0.04
3A (Memphis, TN)	0.22	0.21	0.23	0.02	0.16	0.14	0.17	0.04	0.17	0.08	0.26	0.18	0.15	0.13	0.18	0.04
3B (El Paso, TX)	0.26	0.23	0.28	0.05	0.16	0.14	0.18	0.04	0.19	0.08	0.33	0.25	0.16	0.14	0.18	0.05
BU (Burbank, CA)	0.24	0.22	0.27	0.05	0.16	0.14	0.19	0.04	0.18	0.08	0.30	0.23	0.16	0.14	0.18	0.04
FR (Fresno, CA)	0.23	0.18	0.28	0.10	0.16	0.14	0.17	0.03	0.18	0.08	0.31	0.23	0.16	0.14	0.17	0.03
3C (San Francisco, CA)	0.22	0.20	0.26	0.06	0.16	0.13	0.18	0.05	0.17	0.07	0.28	0.21	0.15	0.14	0.17	0.03
4A (Baltimore, MD)	0.22	0.20	0.23	0.03	0.15	0.11	0.16	0.06	0.15	0.07	0.25	0.18	0.15	0.13	0.17	0.05
4B (Albuquerque, NM)	0.26	0.24	0.29	0.06	0.15	0.13	0.17	0.04	0.18	0.07	0.33	0.26	0.16	0.13	0.19	0.05
4C (Seattle, WA)	0.20	0.17	0.22	0.05	0.15	0.13	0.17	0.04	0.13	0.07	0.21	0.15	0.14	0.12	0.17	0.05
5A (Chicago, IL)	0.20	0.19	0.21	0.03	0.15	0.12	0.16	0.04	0.15	0.07	0.24	0.17	0.15	0.12	0.17	0.04
5B (Boise, ID)	0.23	0.18	0.27	0.09	0.14	0.12	0.16	0.04	0.15	0.06	0.26	0.20	0.14	0.12	0.17	0.05
6A (Burlington, VT)	0.20	0.17	0.21	0.04	0.14	0.12	0.16	0.04	0.14	0.07	0.22	0.15	0.14	0.12	0.16	0.04
6B (Helena, MT)	0.22	0.21	0.24	0.04	0.13	0.12	0.15	0.03	0.14	0.05	0.23	0.18	0.13	0.11	0.15	0.05
7 (Duluth, MN)	0.20	0.19	0.22	0.03	0.14	0.12	0.16	0.04	0.13	0.06	0.22	0.16	0.14	0.12	0.16	0.04
8 (Fairbanks, AK)	0.17	0.14	0.21	0.07	0.09	0.05	0.13	0.08	0.09	0.02	0.16	0.14	0.14	0.08	0.16	0.08
U.S. (excluding CZ 8)	**0.22**	**0.17**	**0.29**	**0.12**	**0.15**	**0.11**	**0.19**	**0.08**	**0.16**	**0.05**	**0.33**	**0.28**	**0.15**	**0.11**	**0.19**	**0.08**



ESM Figure B-1. Monthly SAF versus latitude and canyon aspect ratio R for (a) north, (b) east, (c) south, or (d) west conventional central wall (ρ=0.25) facing neighboring cool wall (ρ=0.60). Marker is annual mean; bars bound annual minimum and maximum values.

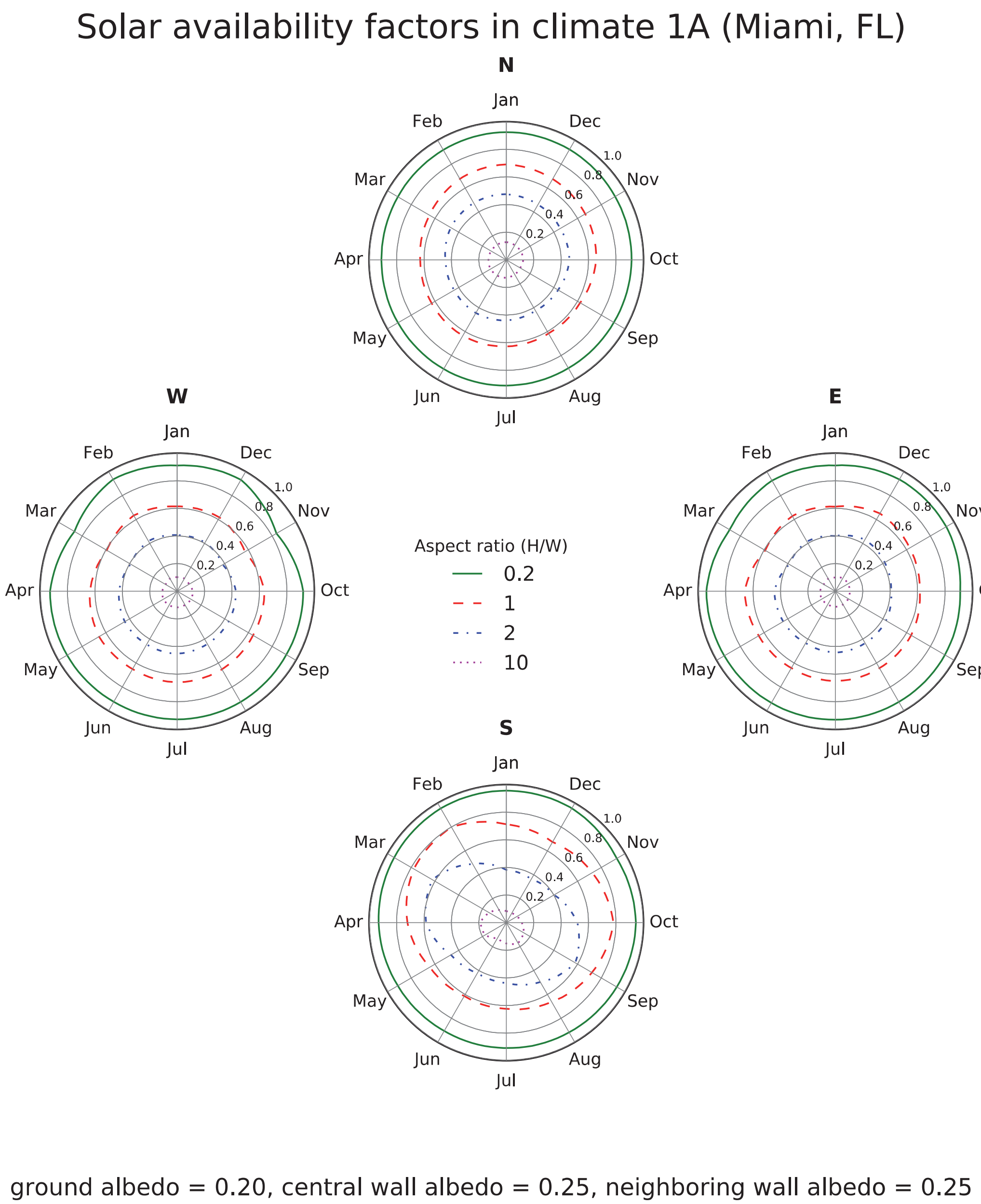


ESM Figure B-2. Same as ESM Figure B-1, but for cool central wall (ρ=0.60) facing conventional neighboring wall (ρ=0.25).



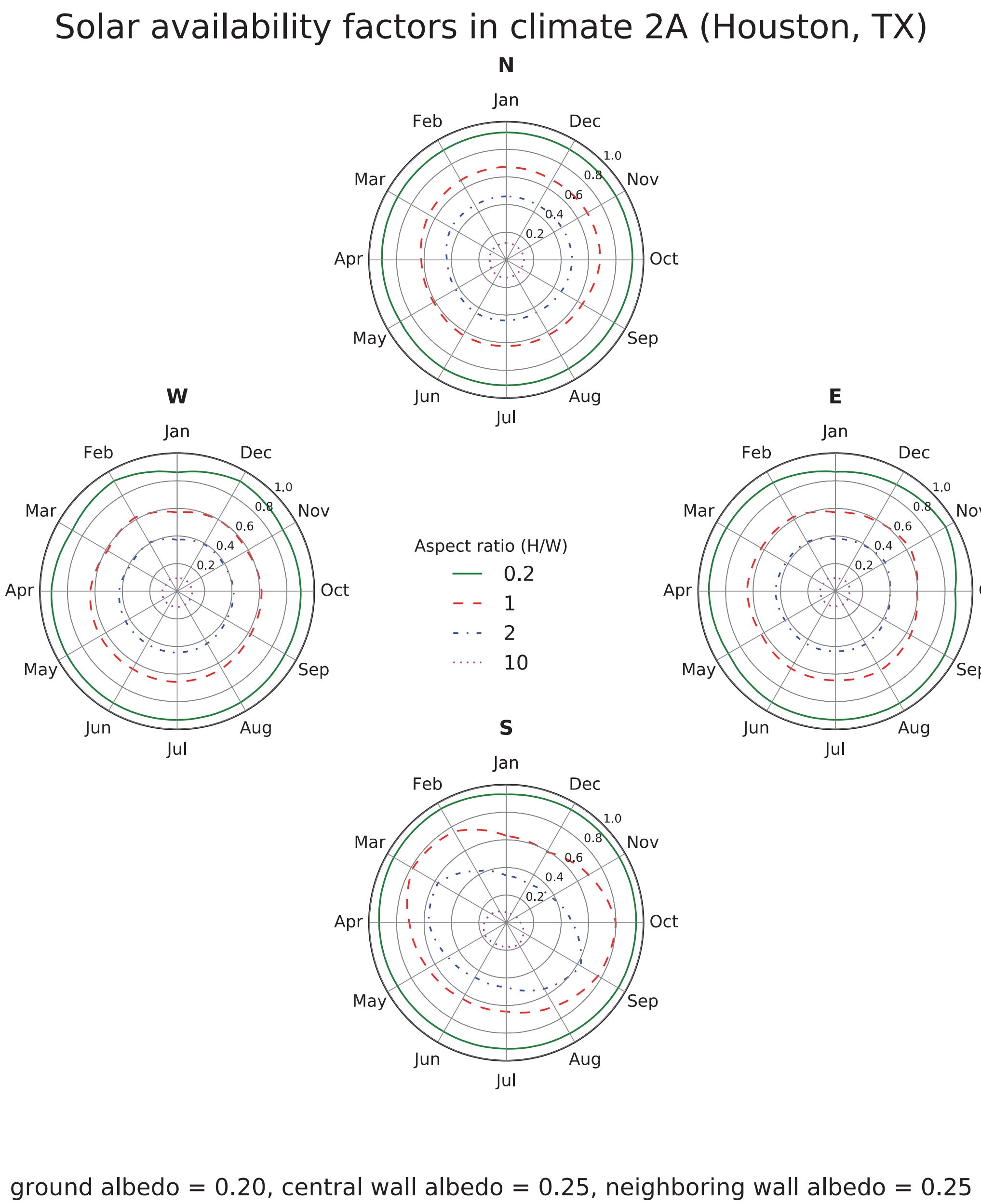
ESM Figure B-3. Same as ESM Figure B-1, but for cool central wall (ρ=0.60) facing cool neighboring wall (ρ=0.60).

ESM Appendix C: Monthly SAF plots by climate zone



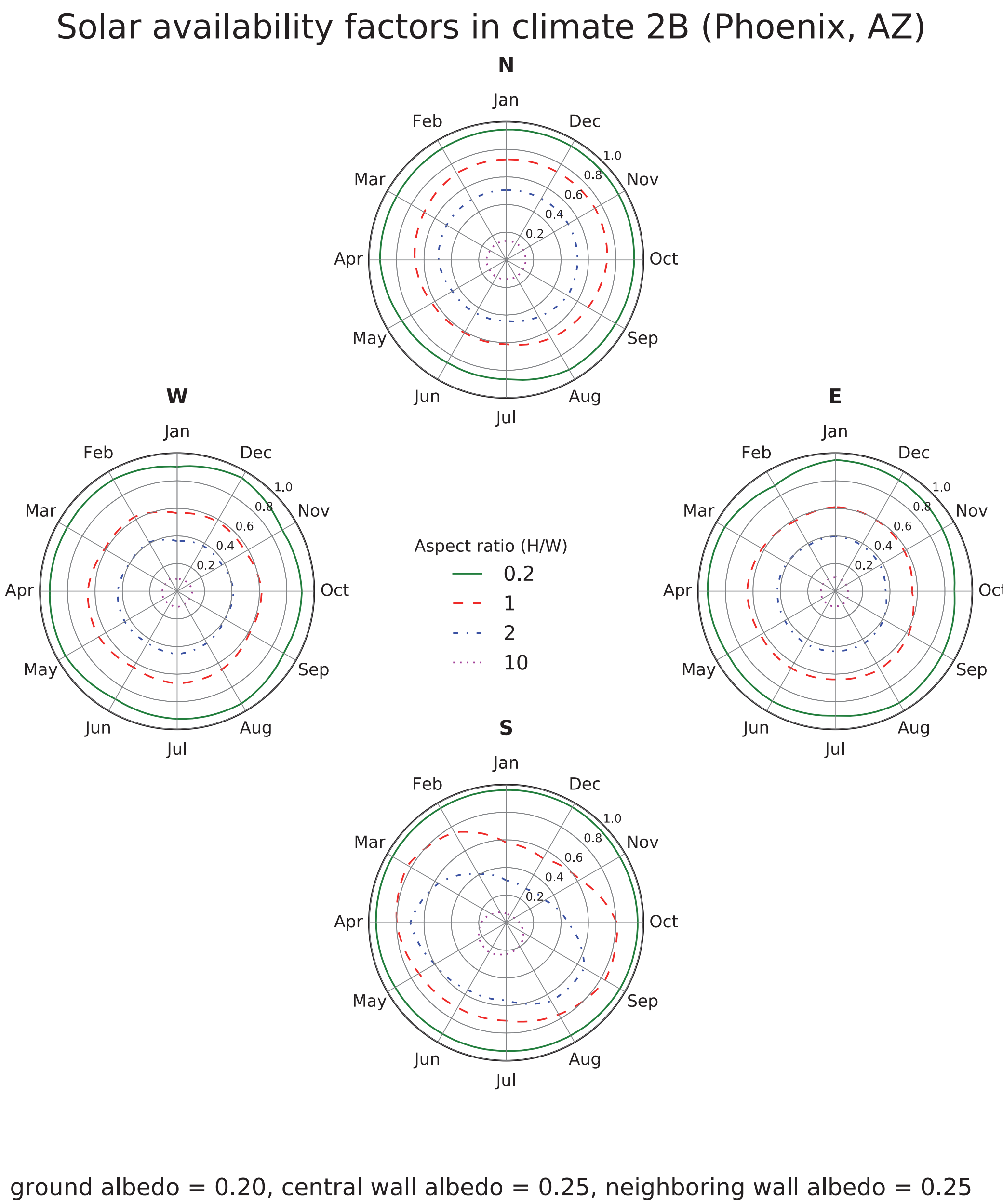
(a)

ESM Figure C-1. Monthly SAFs for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) with a conventional neighboring wall (ρ=0.25). Results shown for aspect ratios 0.2, 1, 2, and 10 in each of 17 climates (panels a through q).



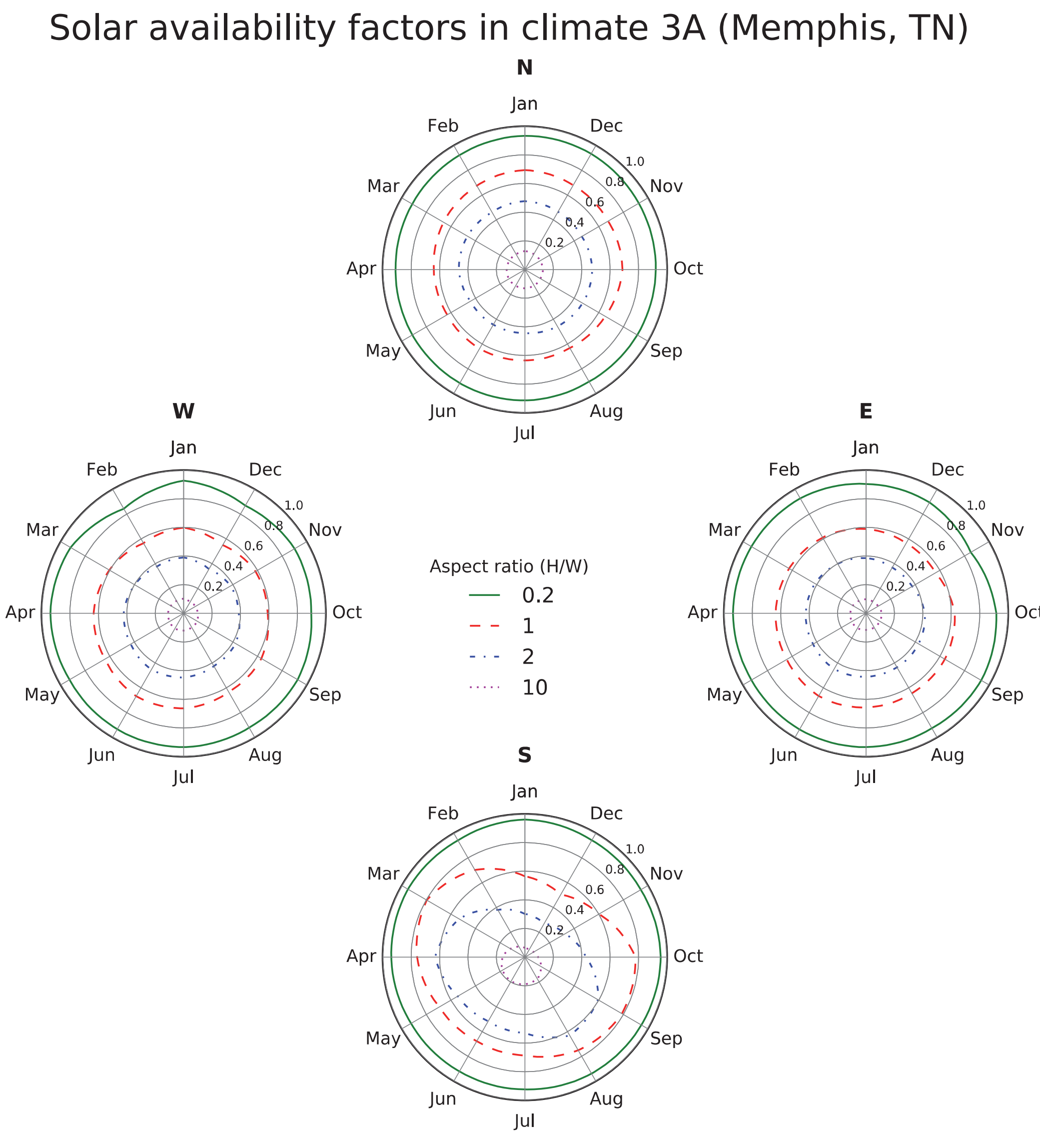
(b)

ESM Figure C-1 (continued)



(c)

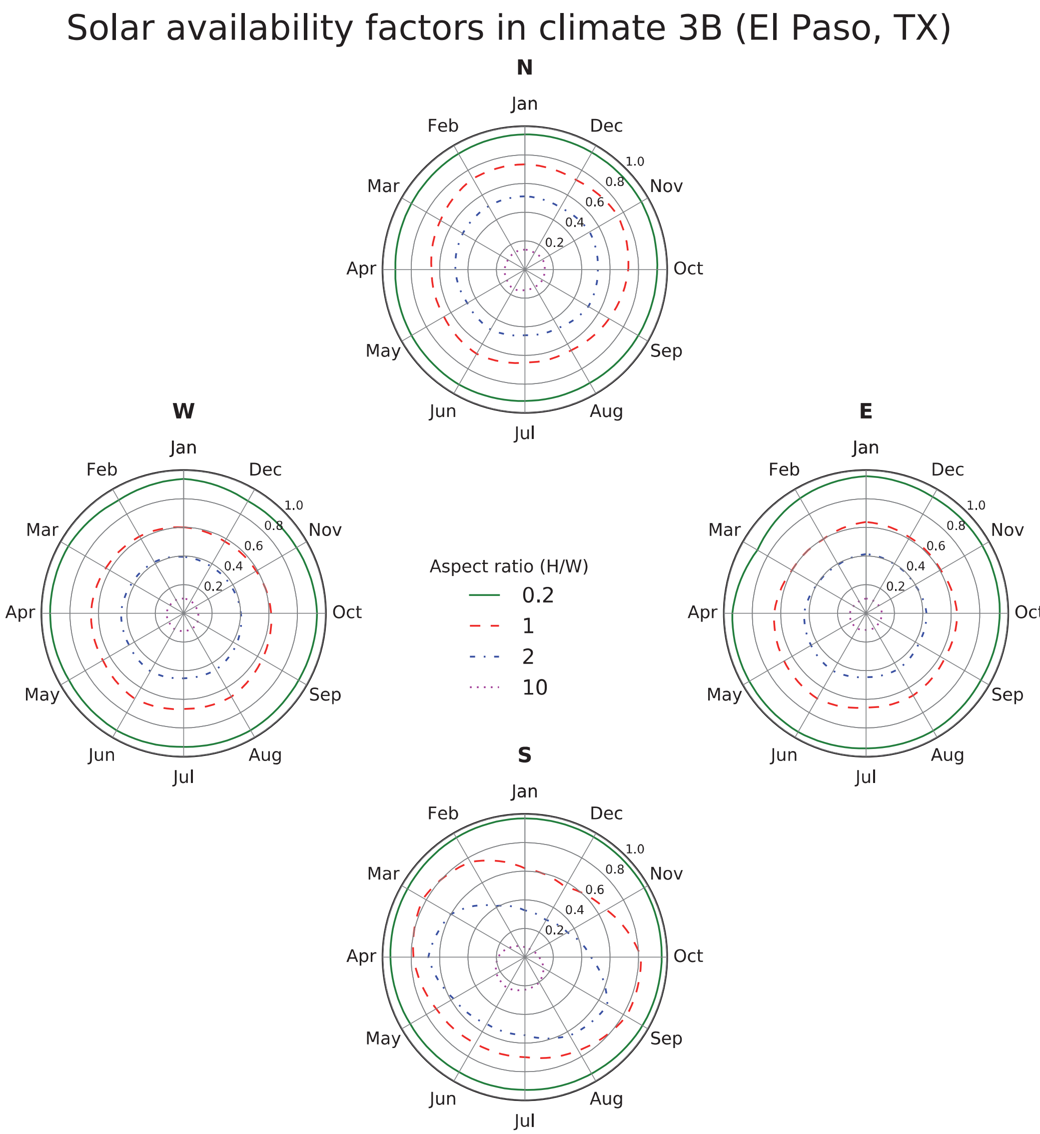
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(d)

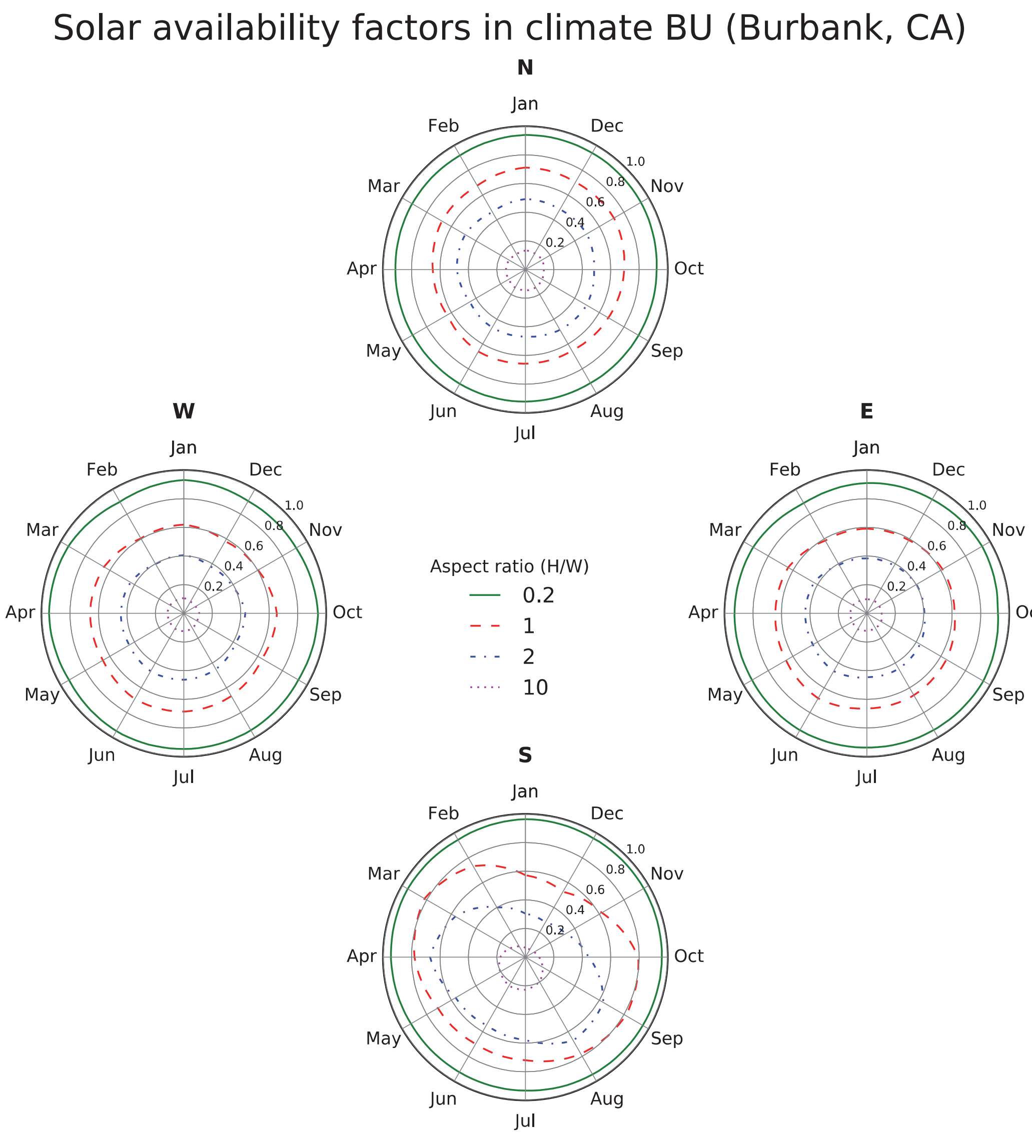
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(e)

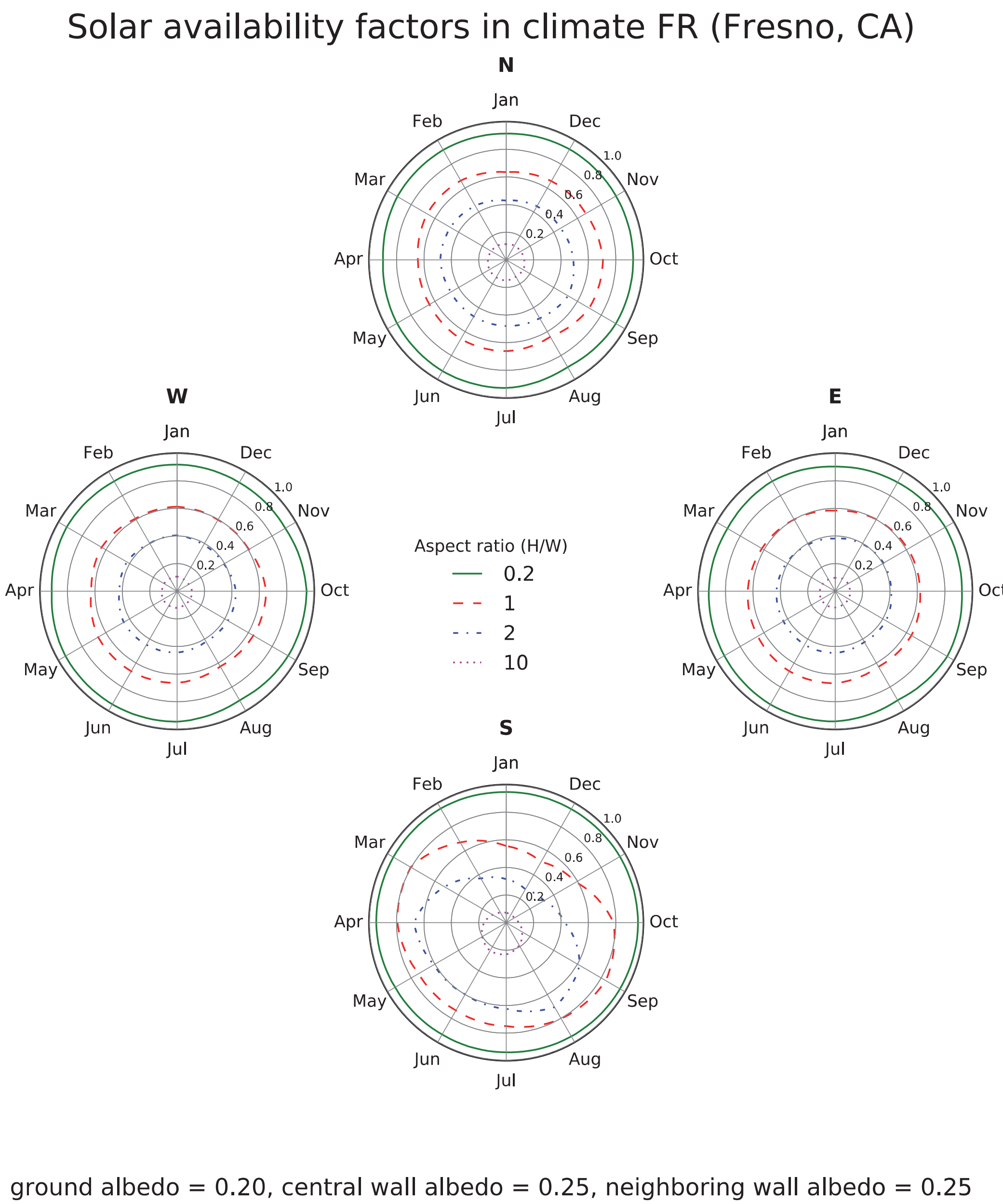
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

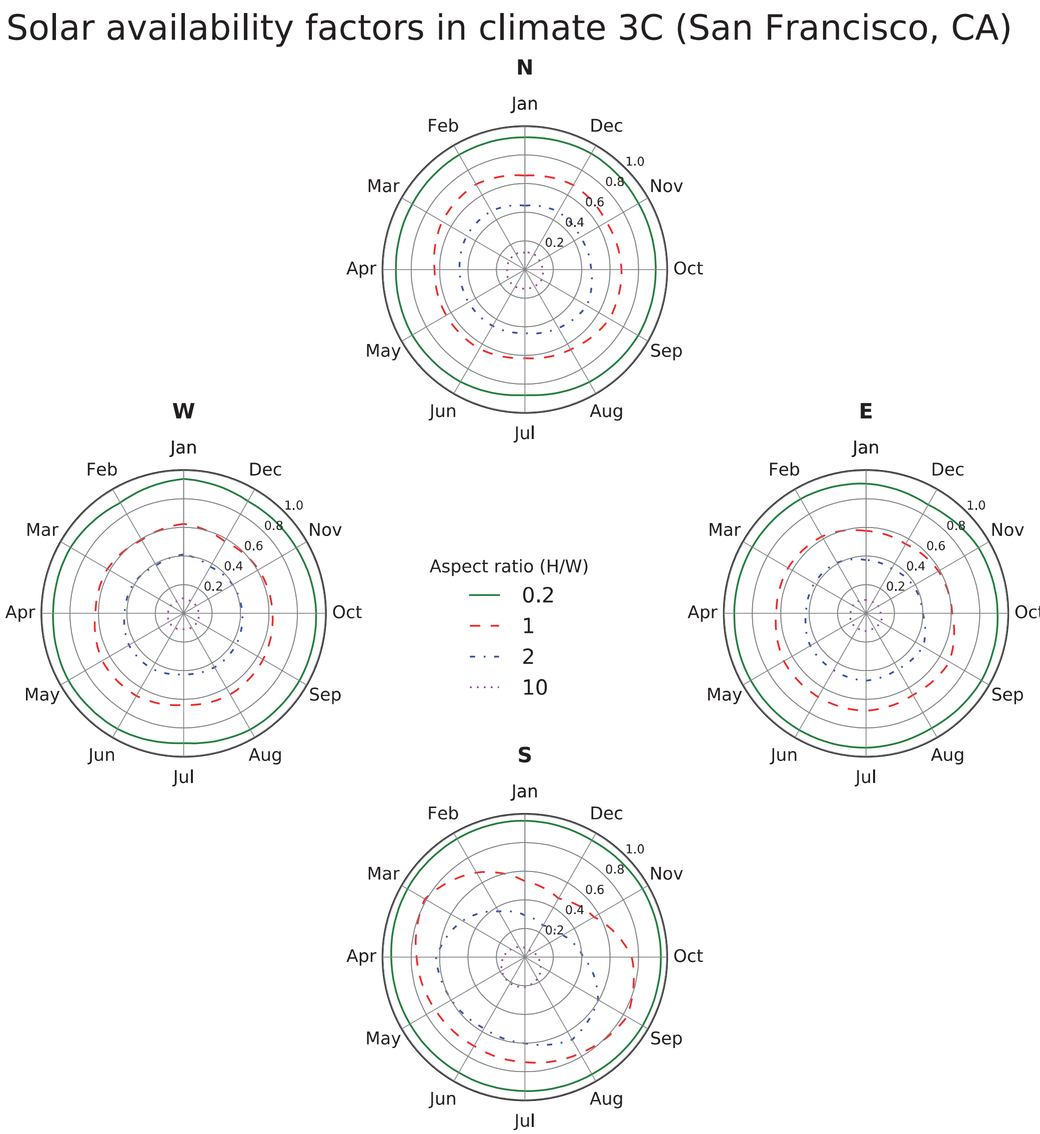
(f)

ESM Figure C-1 (continued)



(g)

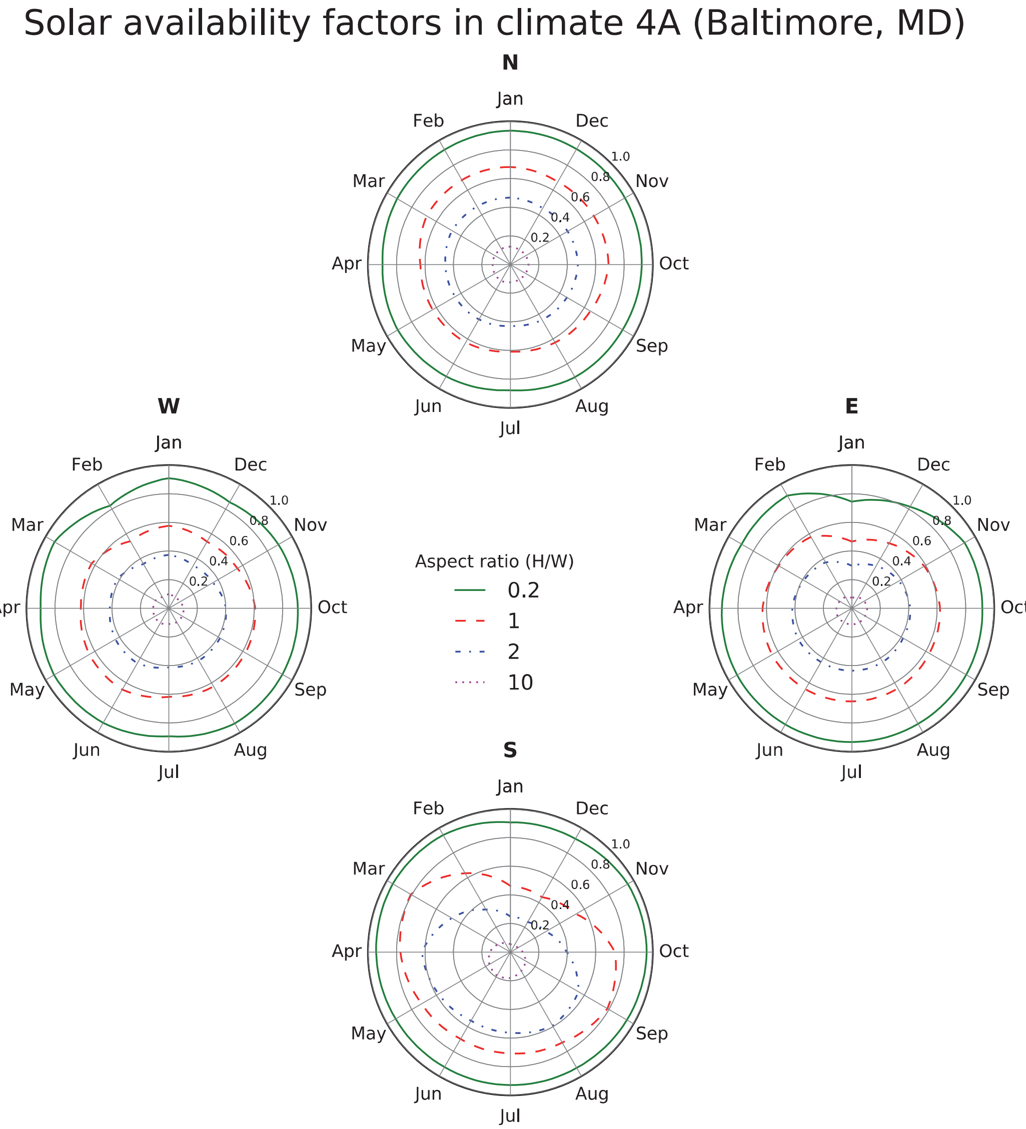
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(h)

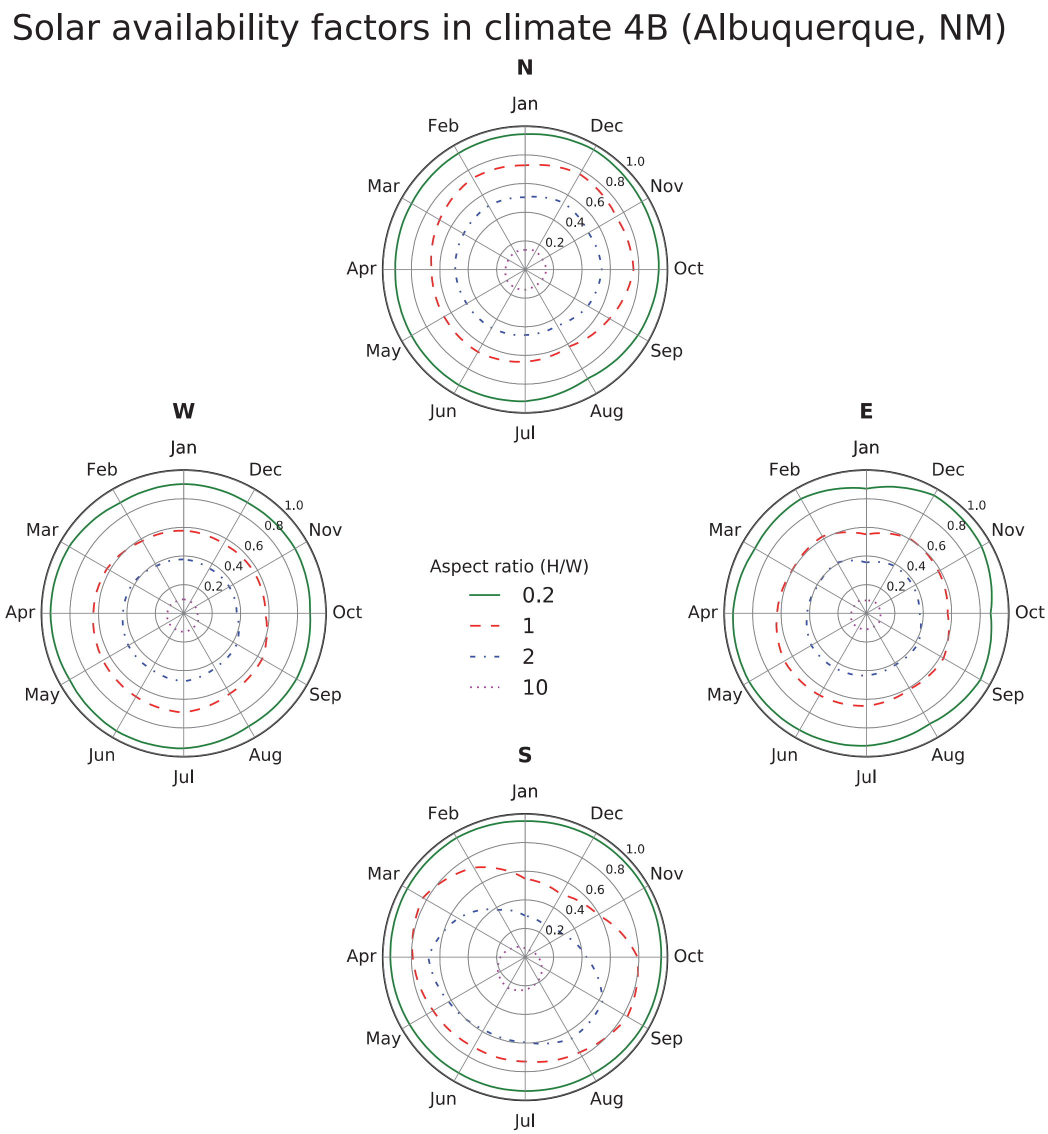
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(i)

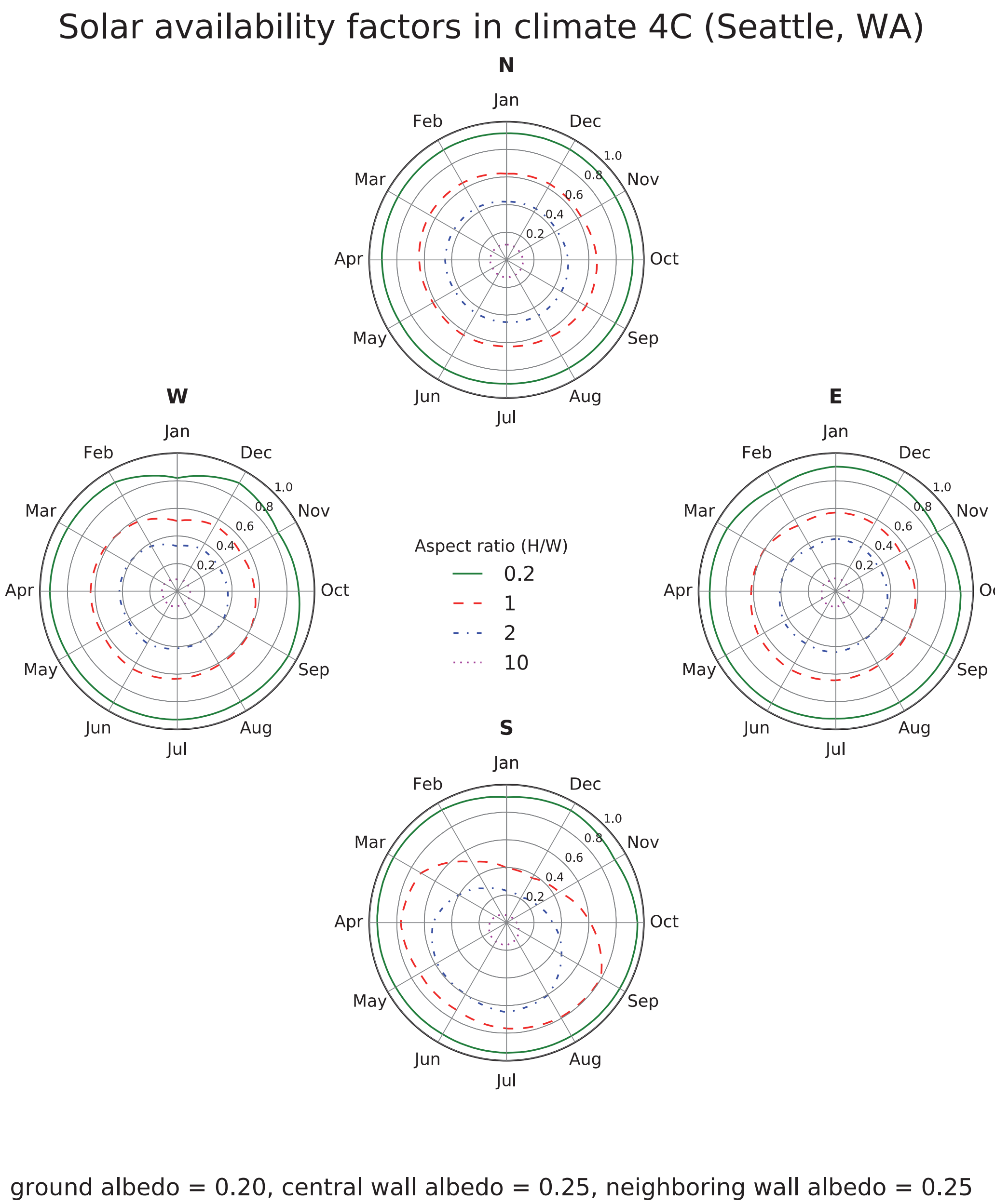
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(j)

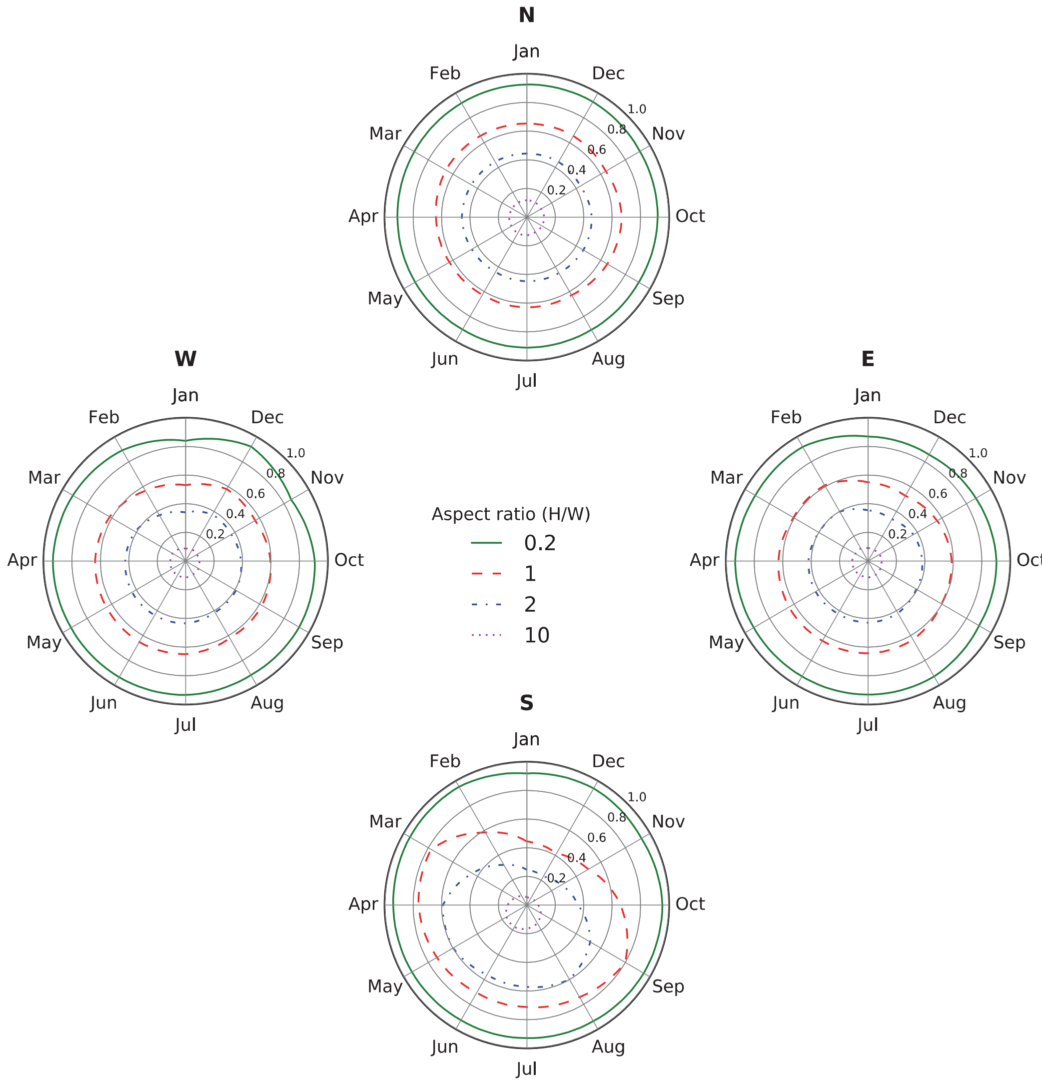
ESM Figure C-1 (continued)



(k)

ESM Figure C-1 (continued)

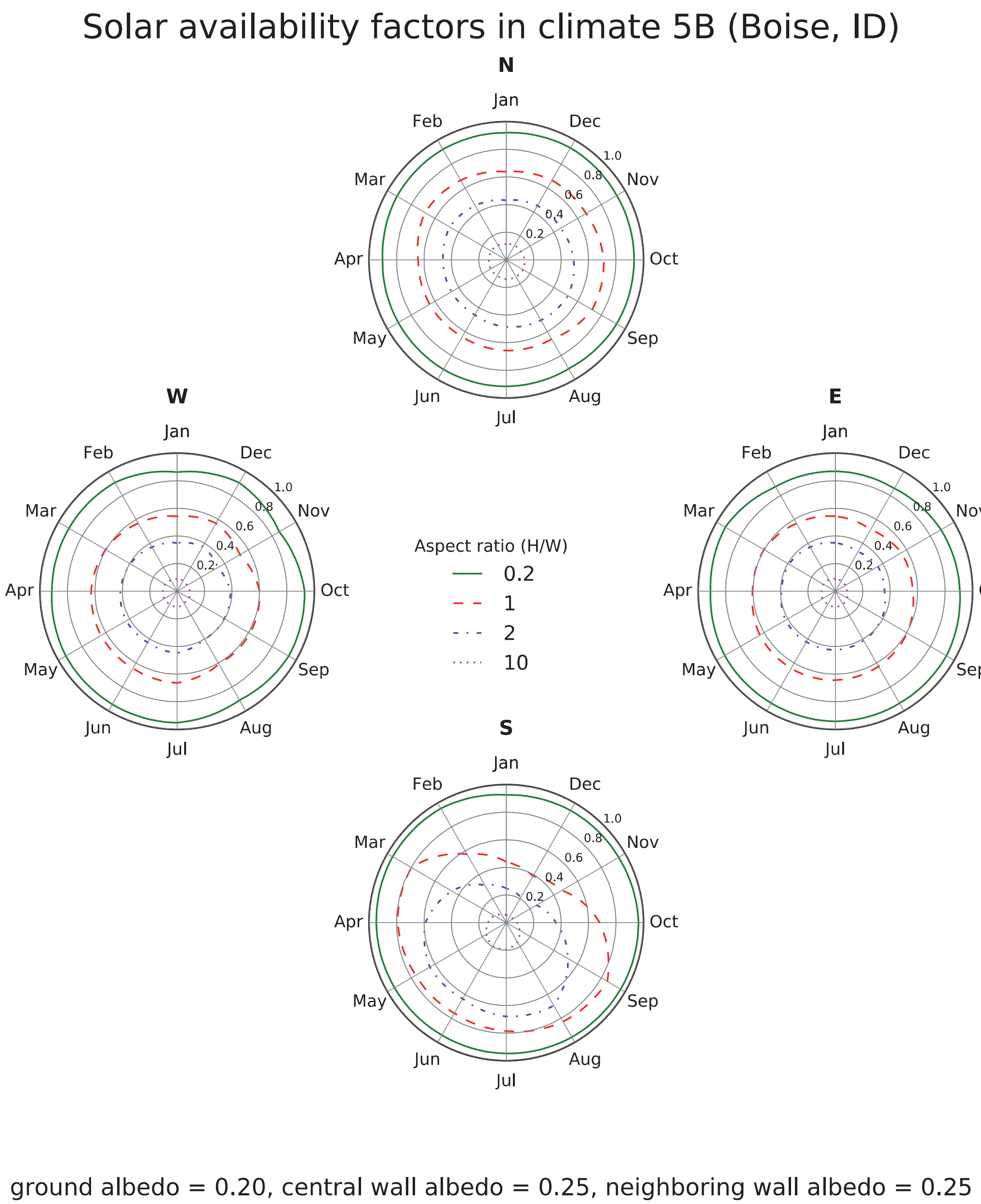
Solar availability factors in climate 5A (Chicago, IL)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(l)

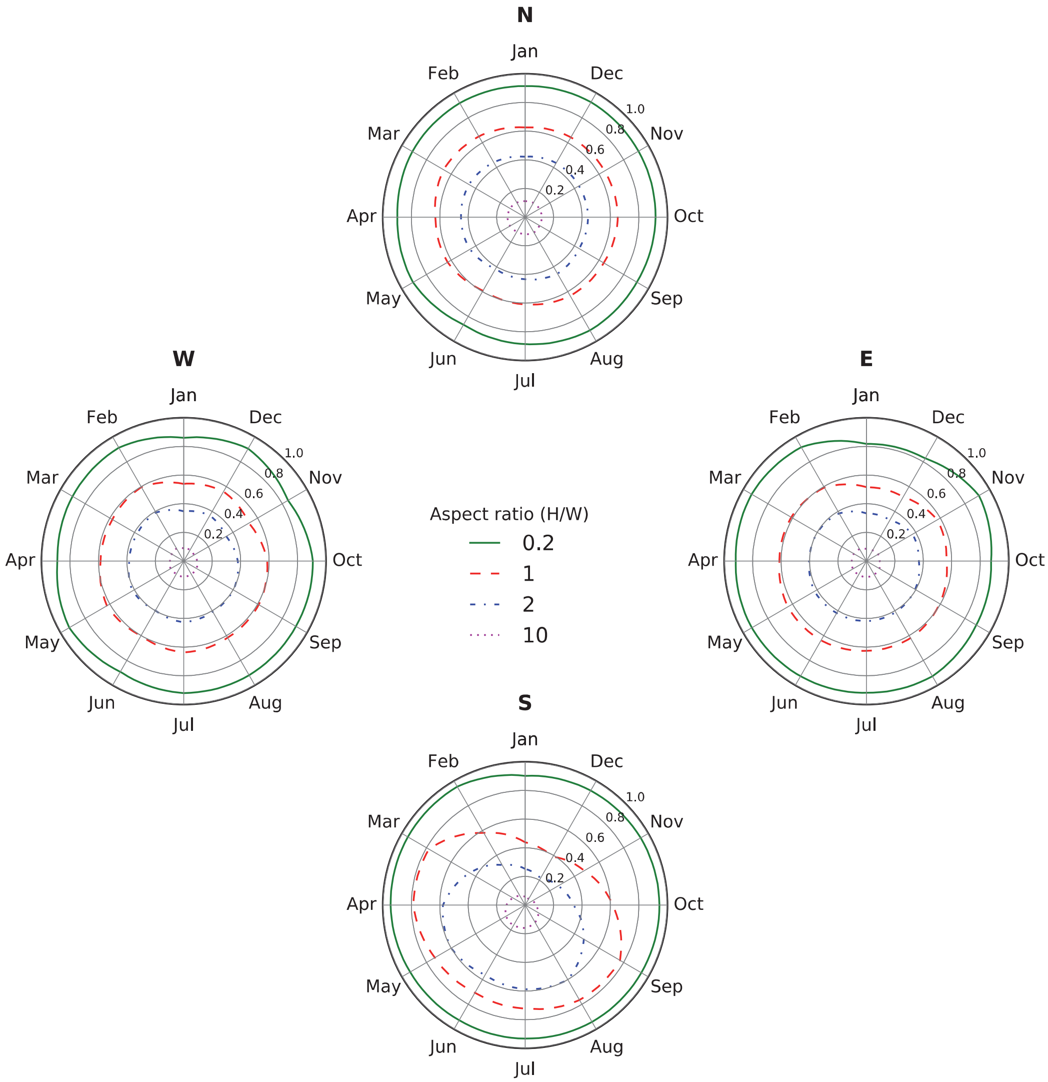
ESM Figure C-1 (continued)



(m)

ESM Figure C-1 (continued)

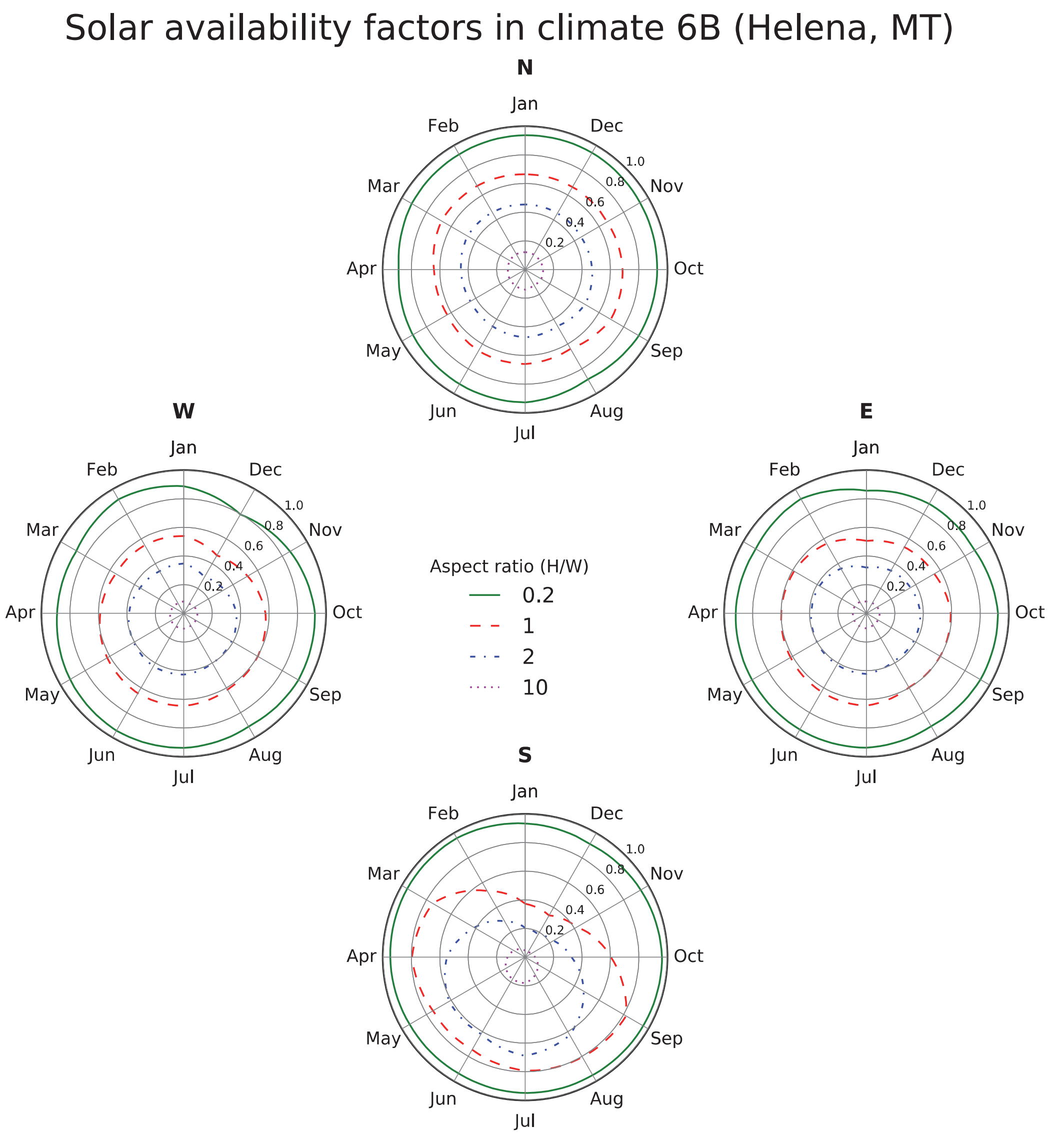
Solar availability factors in climate 6A (Burlington, VT)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

(n)

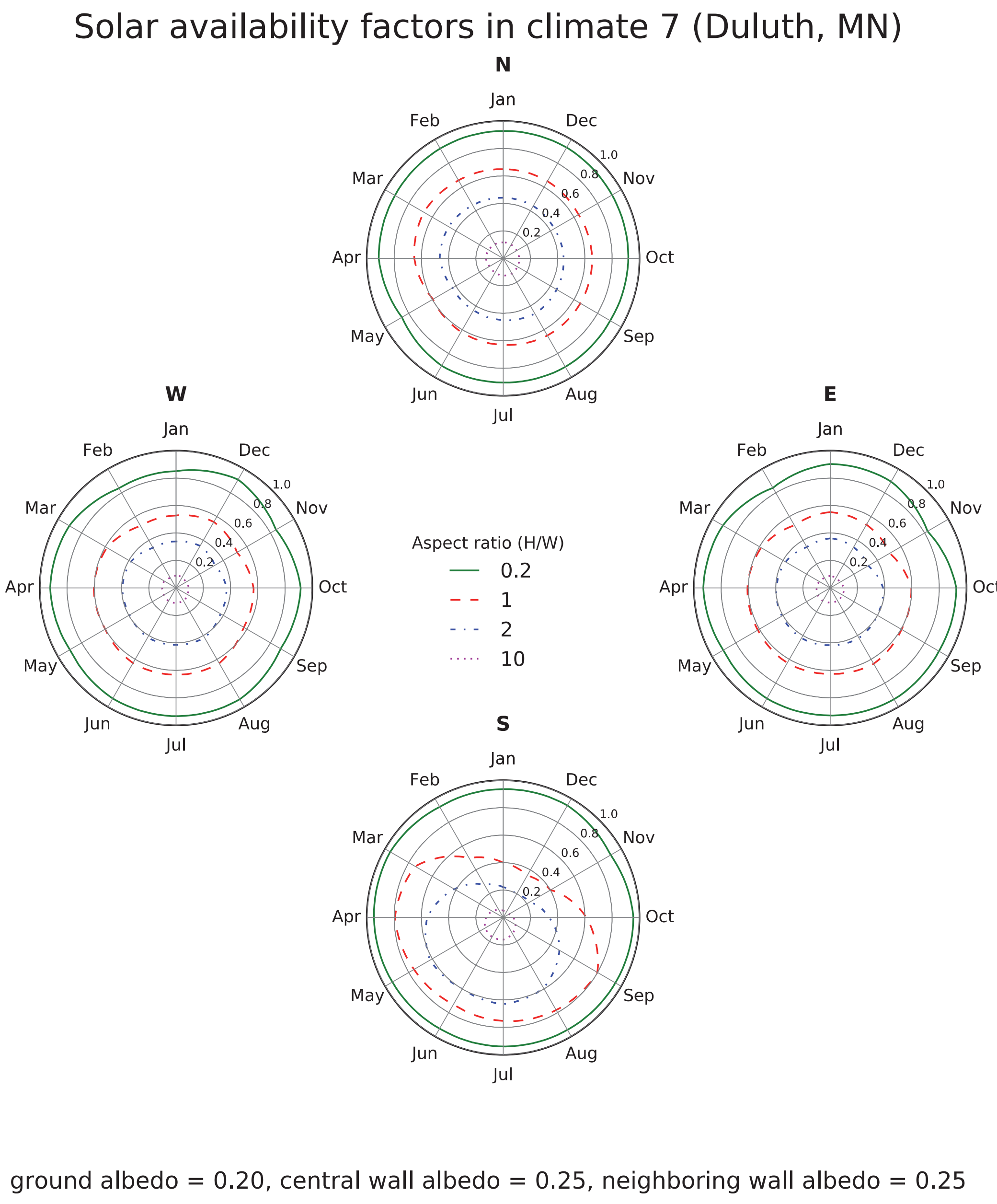
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

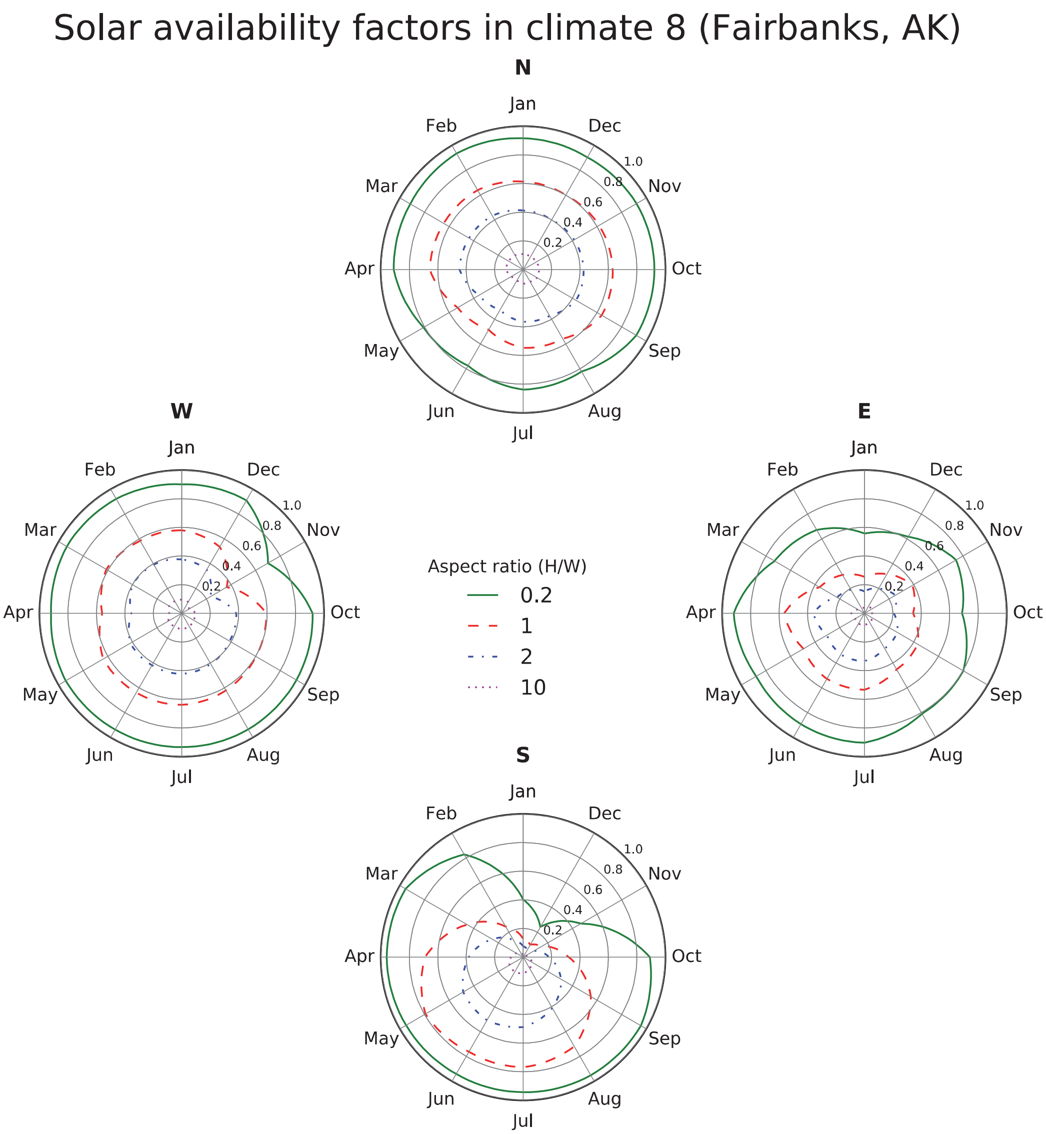
(o)

ESM Figure C-1 (continued)



(p)

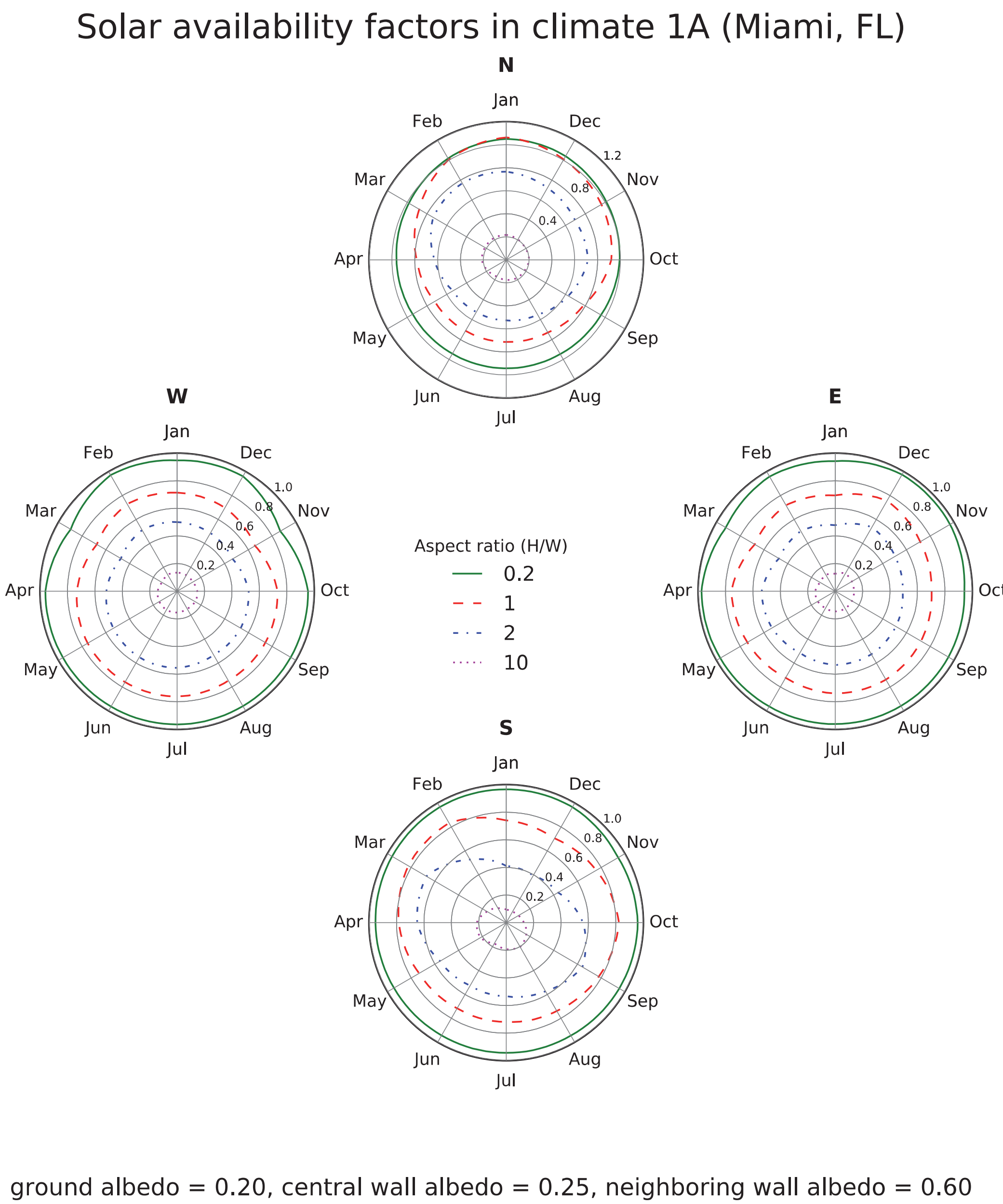
ESM Figure C-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.25

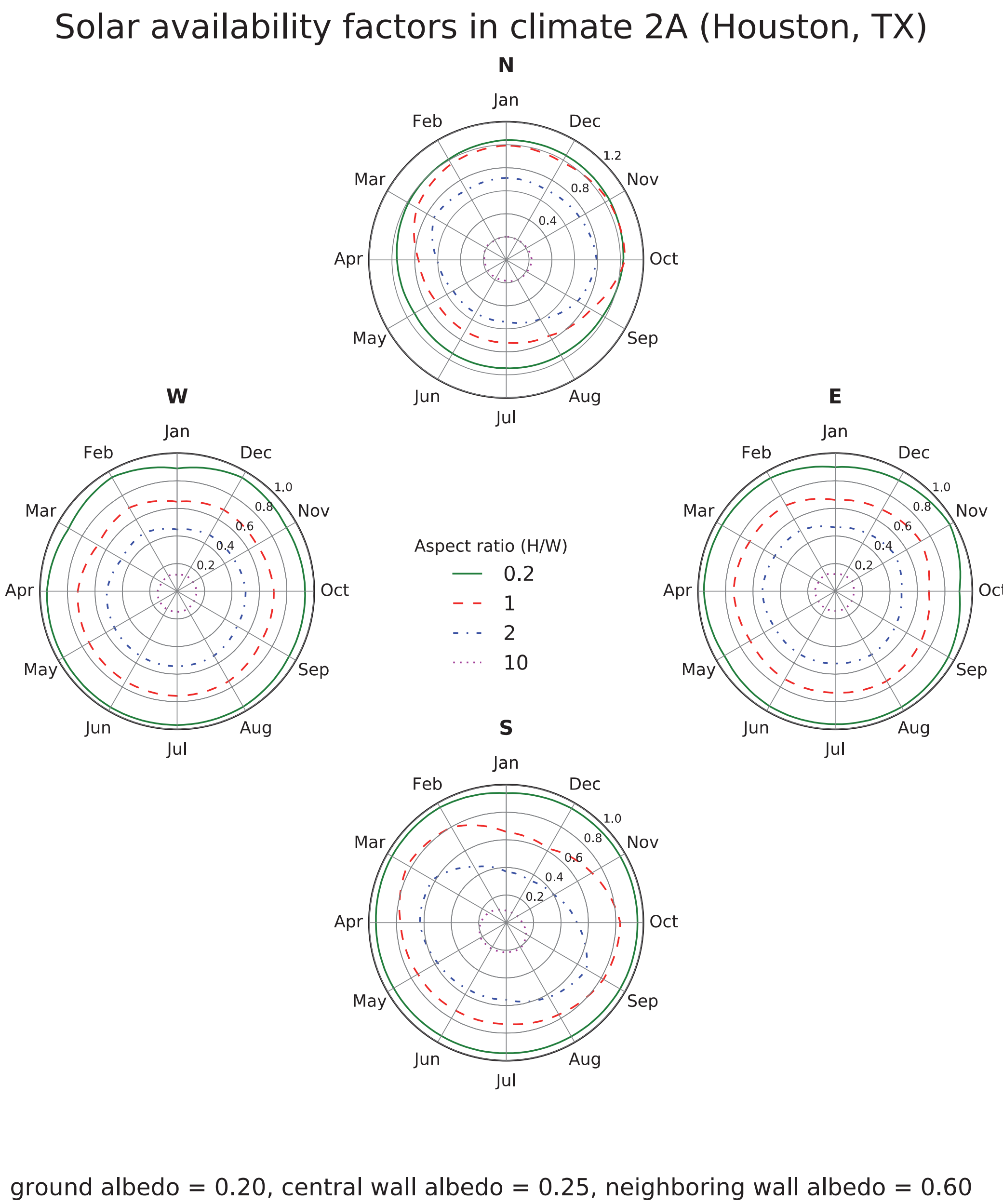
(q)

ESM Figure C-1 (continued)



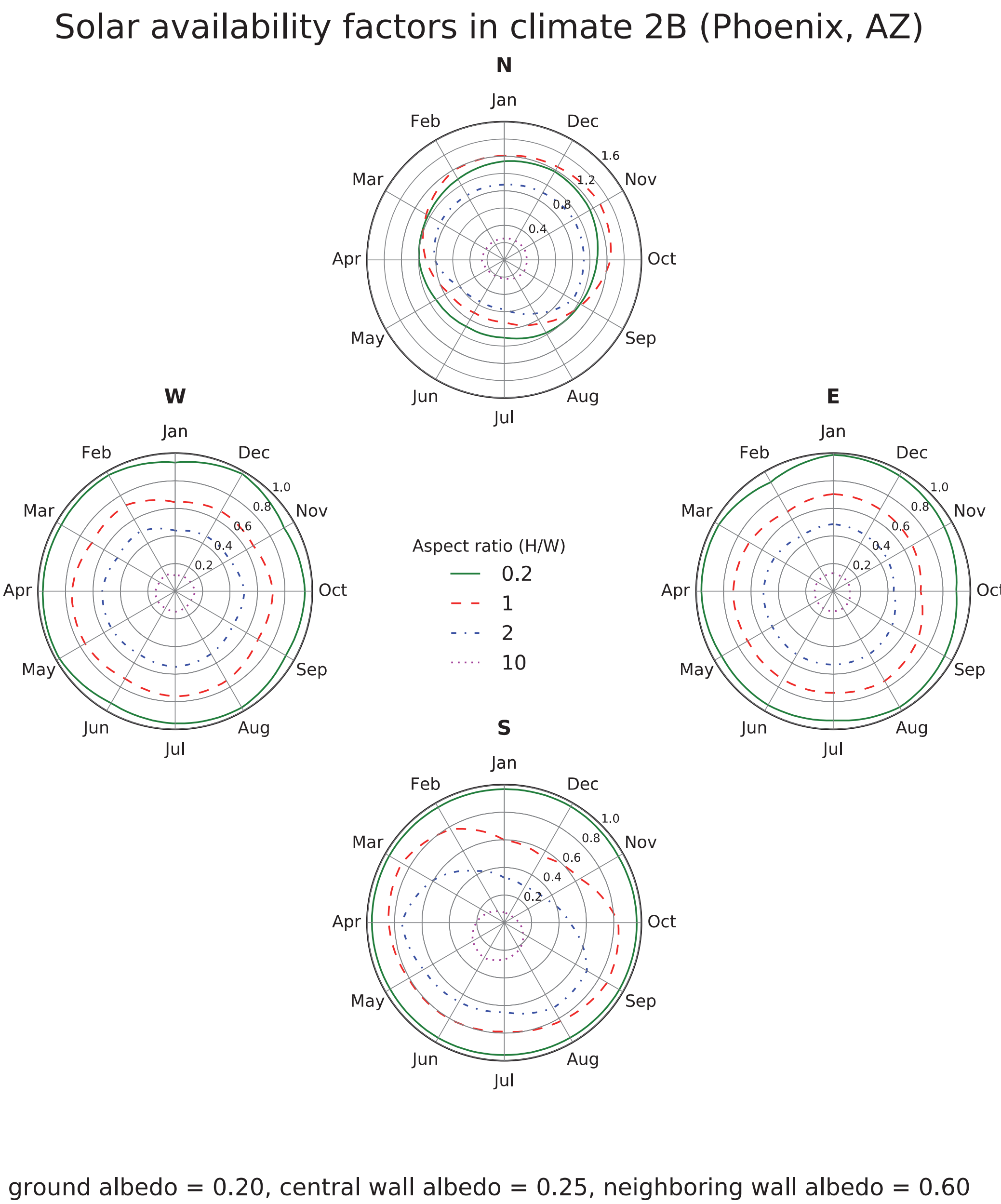
(a)

ESM Figure C-2. Monthly SAFs for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) with a cool neighboring wall (ρ=0.60). Results shown for aspect ratios 0.2, 1, 2, and 10 in each of 17 climates (panels a through q).



(b)

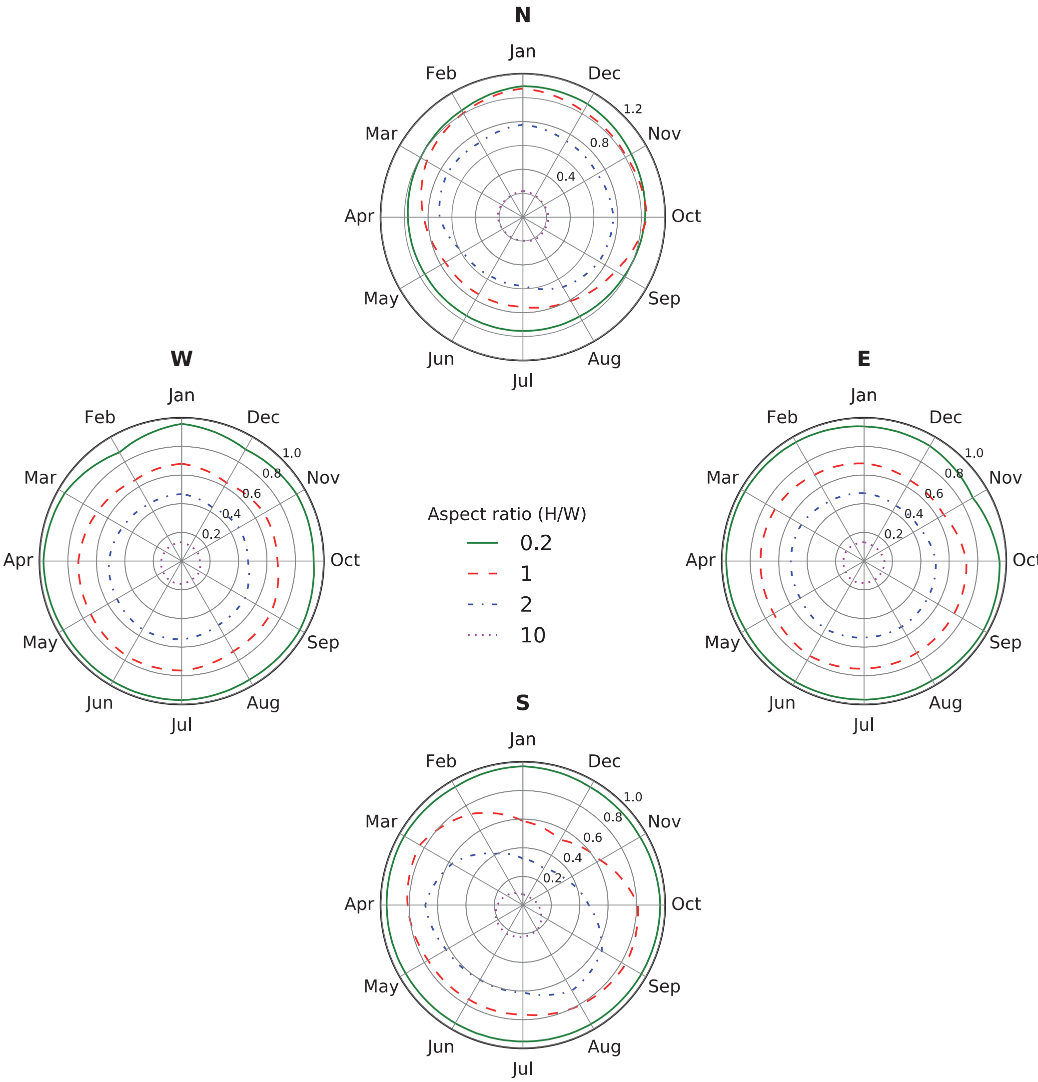
ESM Figure C-2 (continued)



(c)

ESM Figure C-2 (continued)

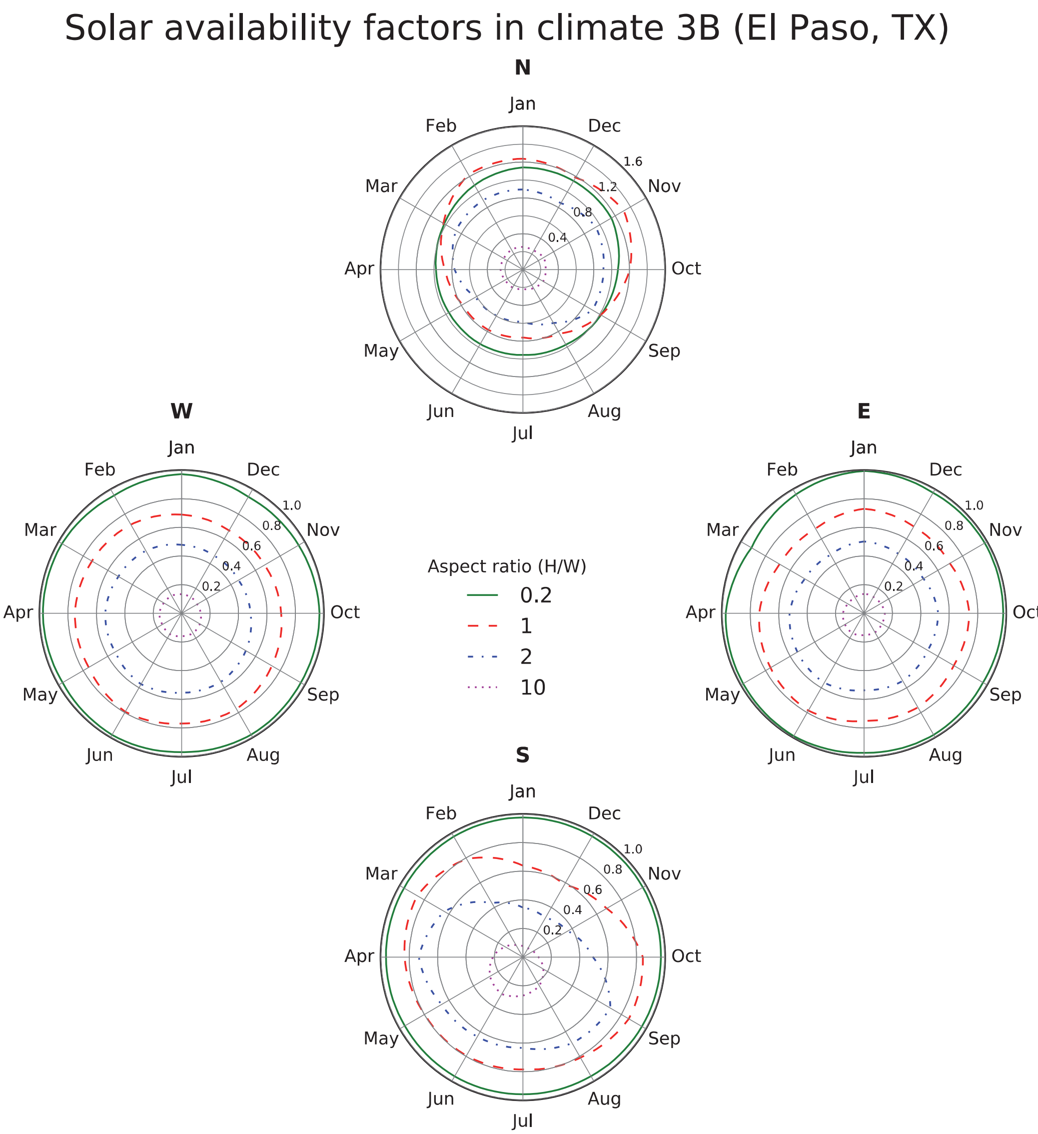
Solar availability factors in climate 3A (Memphis, TN)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(d)

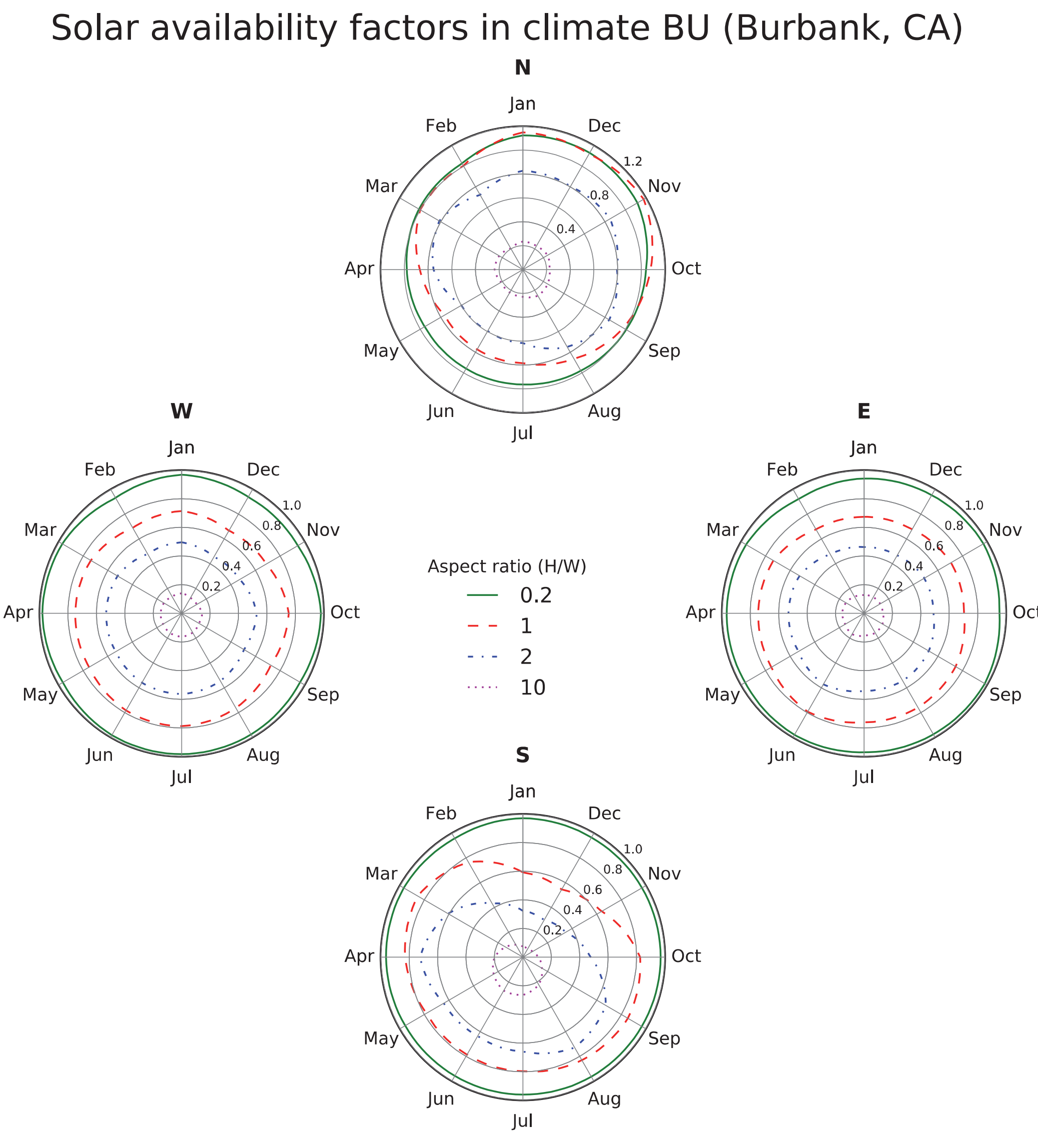
ESM Figure C-2 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(e)

ESM Figure C-2 (continued)

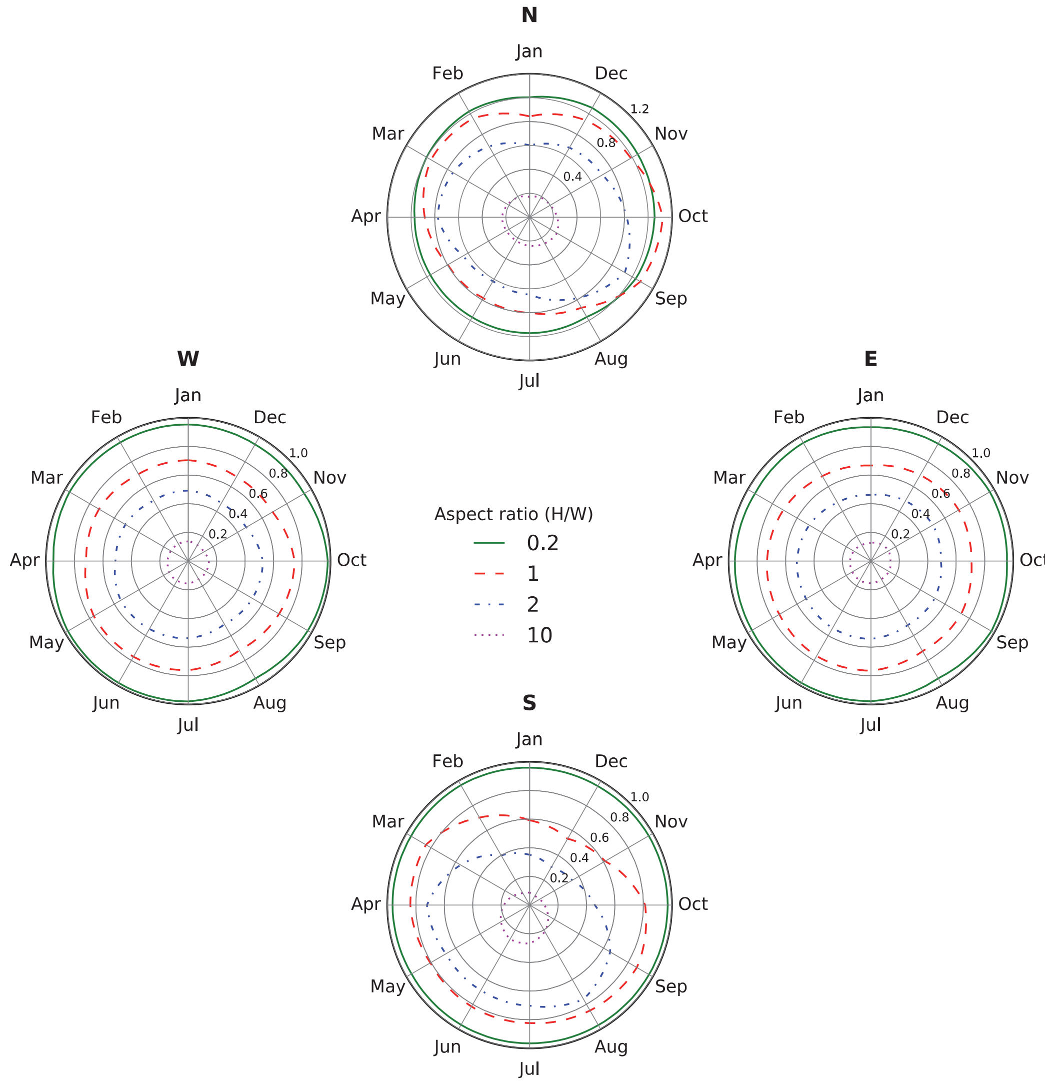


ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(f)

ESM Figure C-2 (continued)

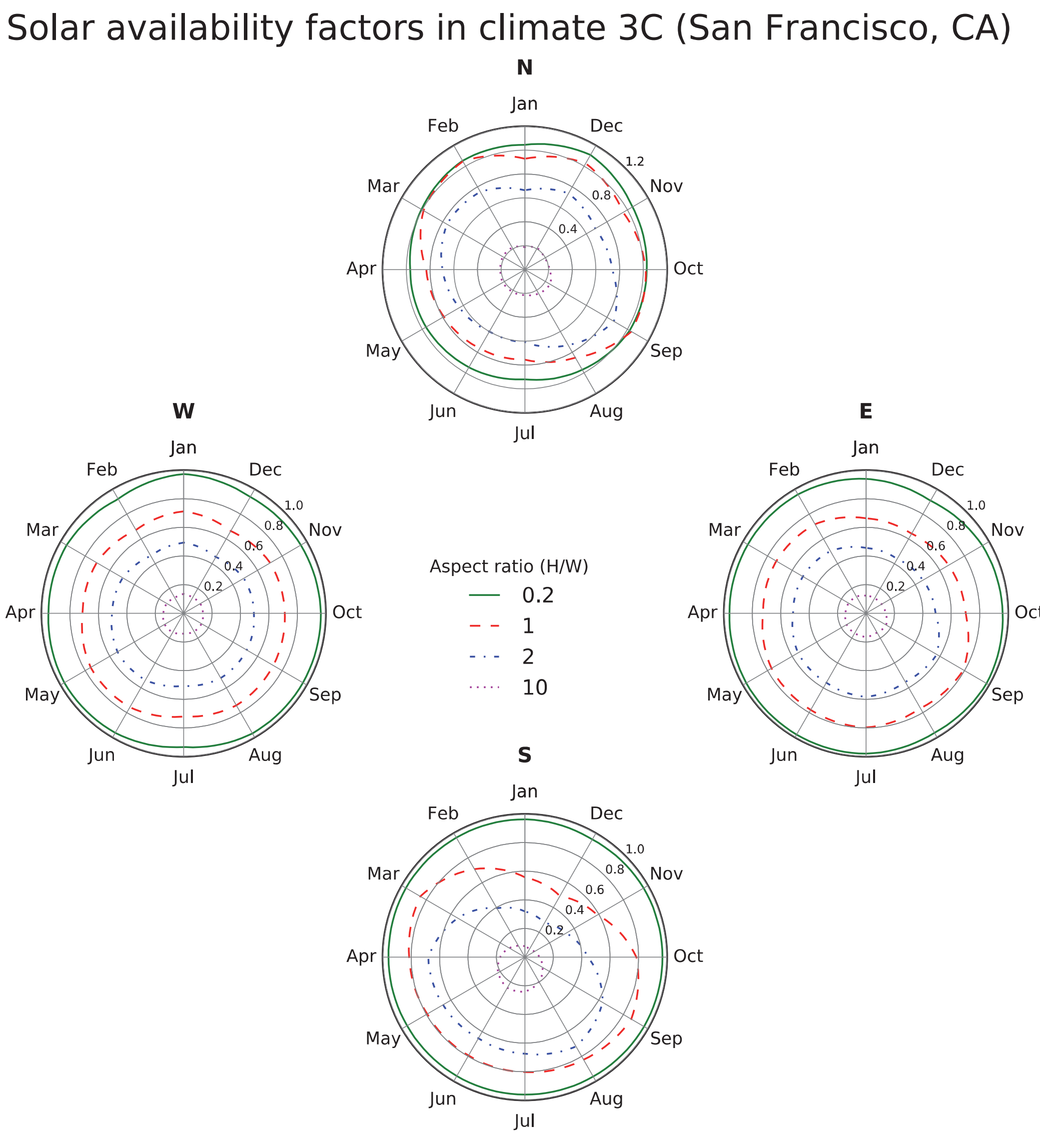
Solar availability factors in climate FR (Fresno, CA)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(g)

ESM Figure C-2 (continued)

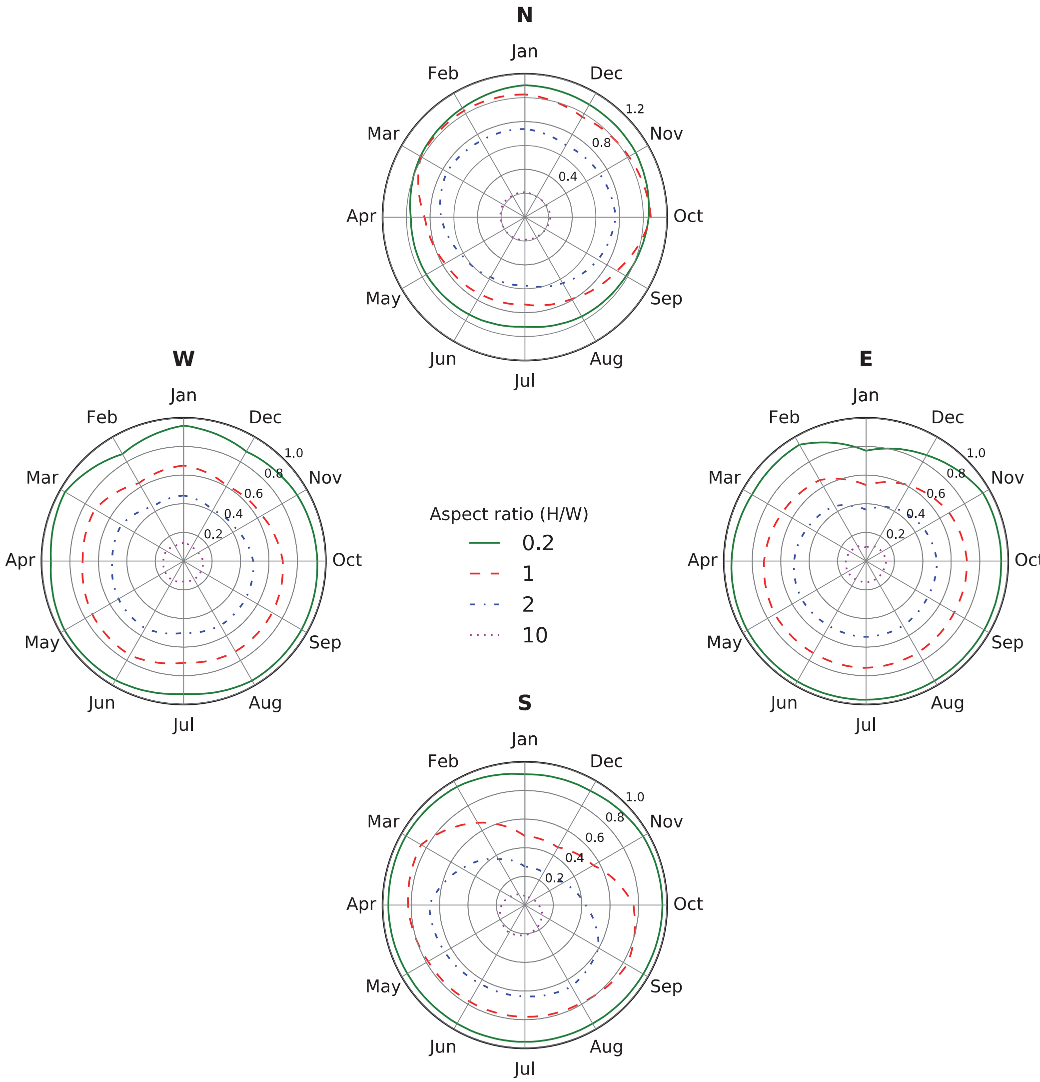


ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(h)

ESM Figure C-2 (continued)

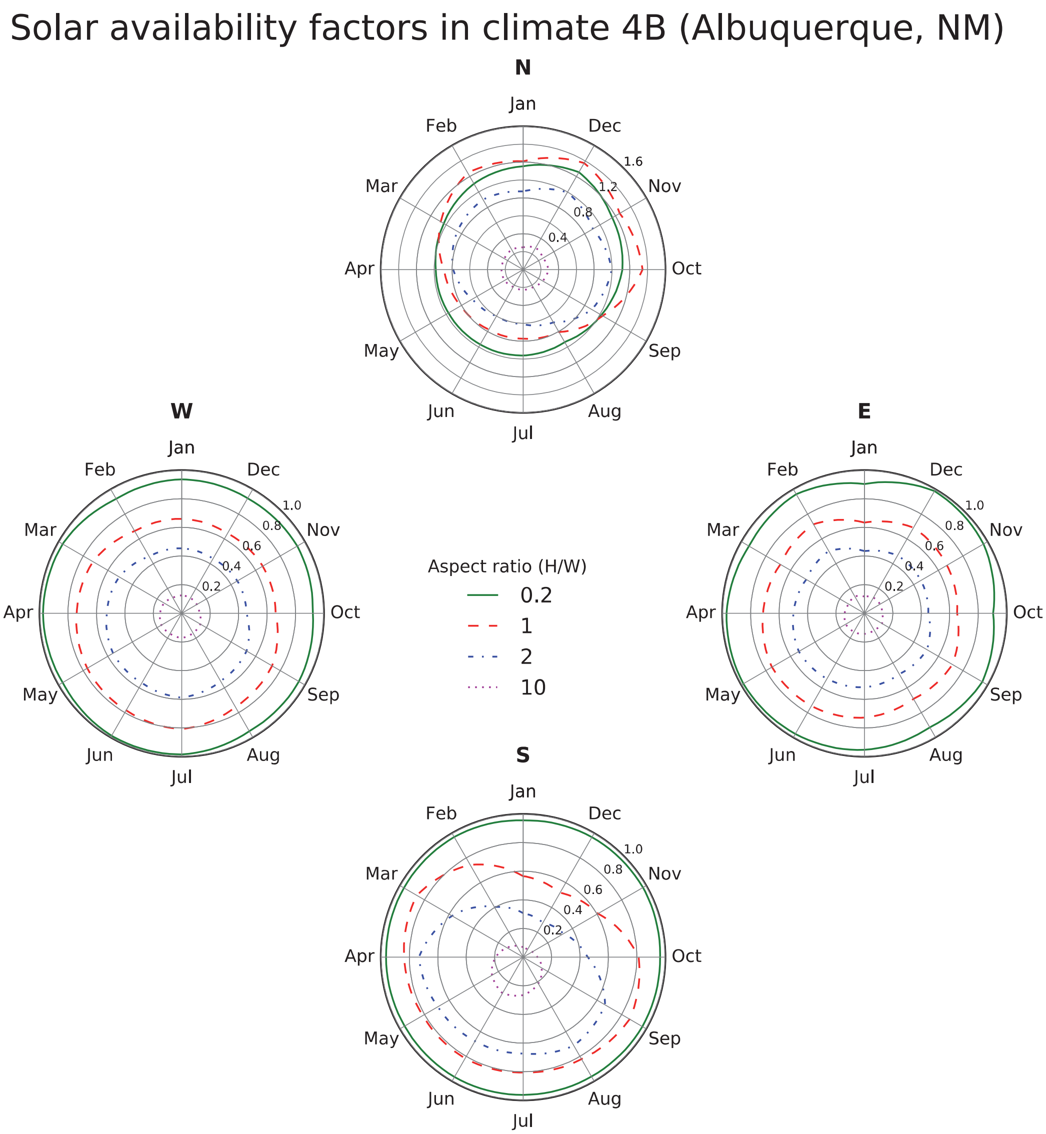
Solar availability factors in climate 4A (Baltimore, MD)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(i)

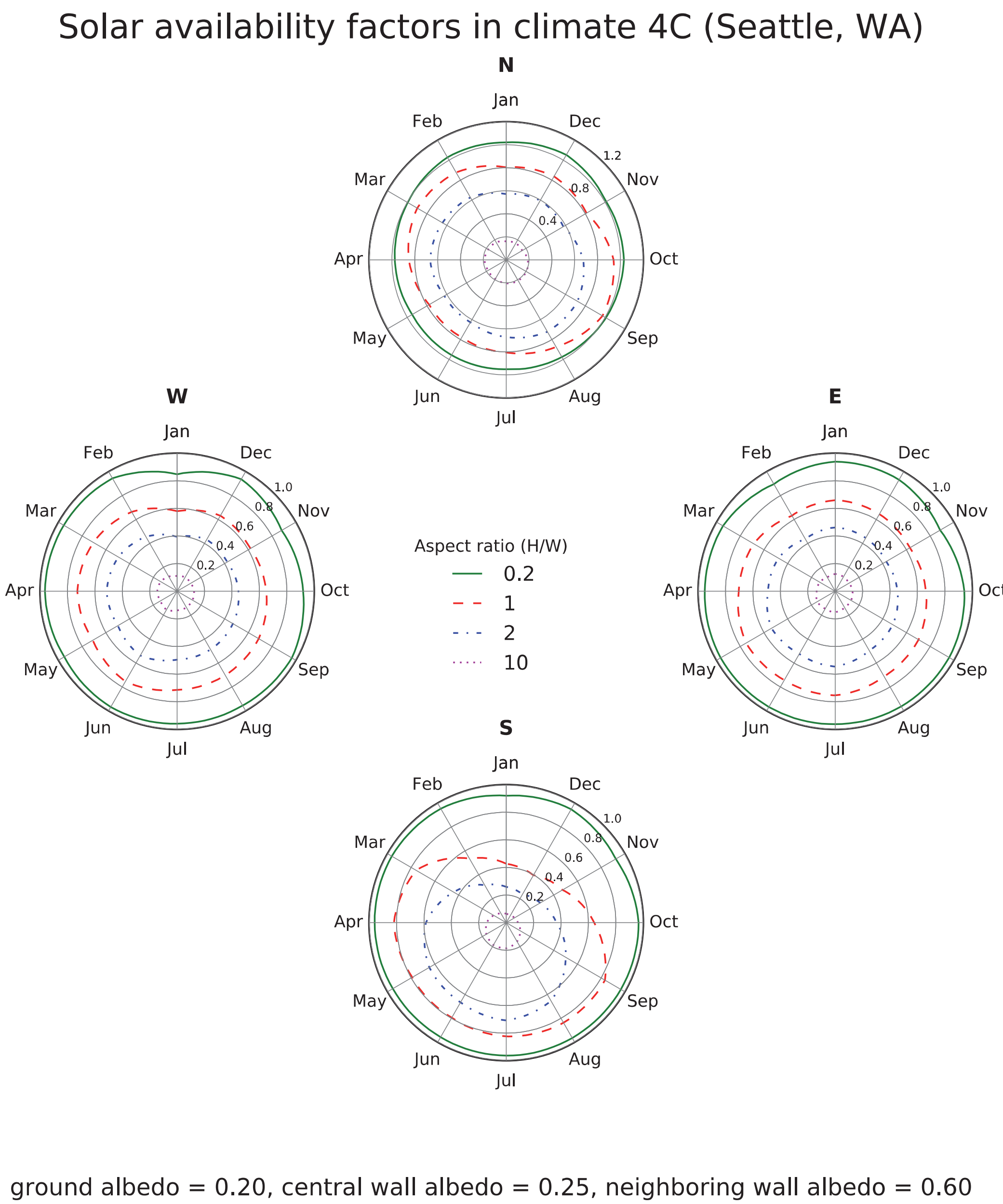
ESM Figure C-2 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

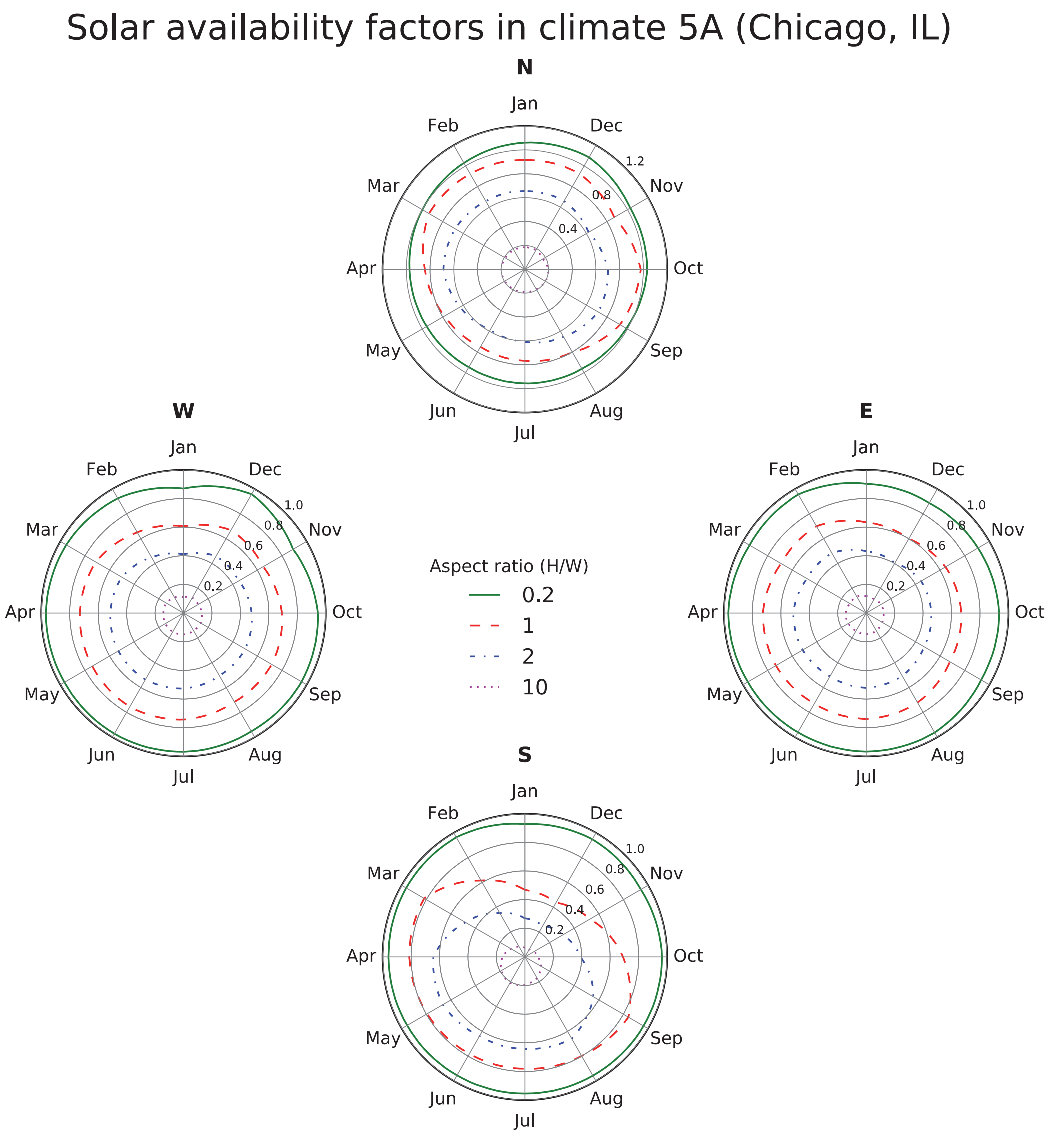
(j)

ESM Figure C-2 (continued)



(k)

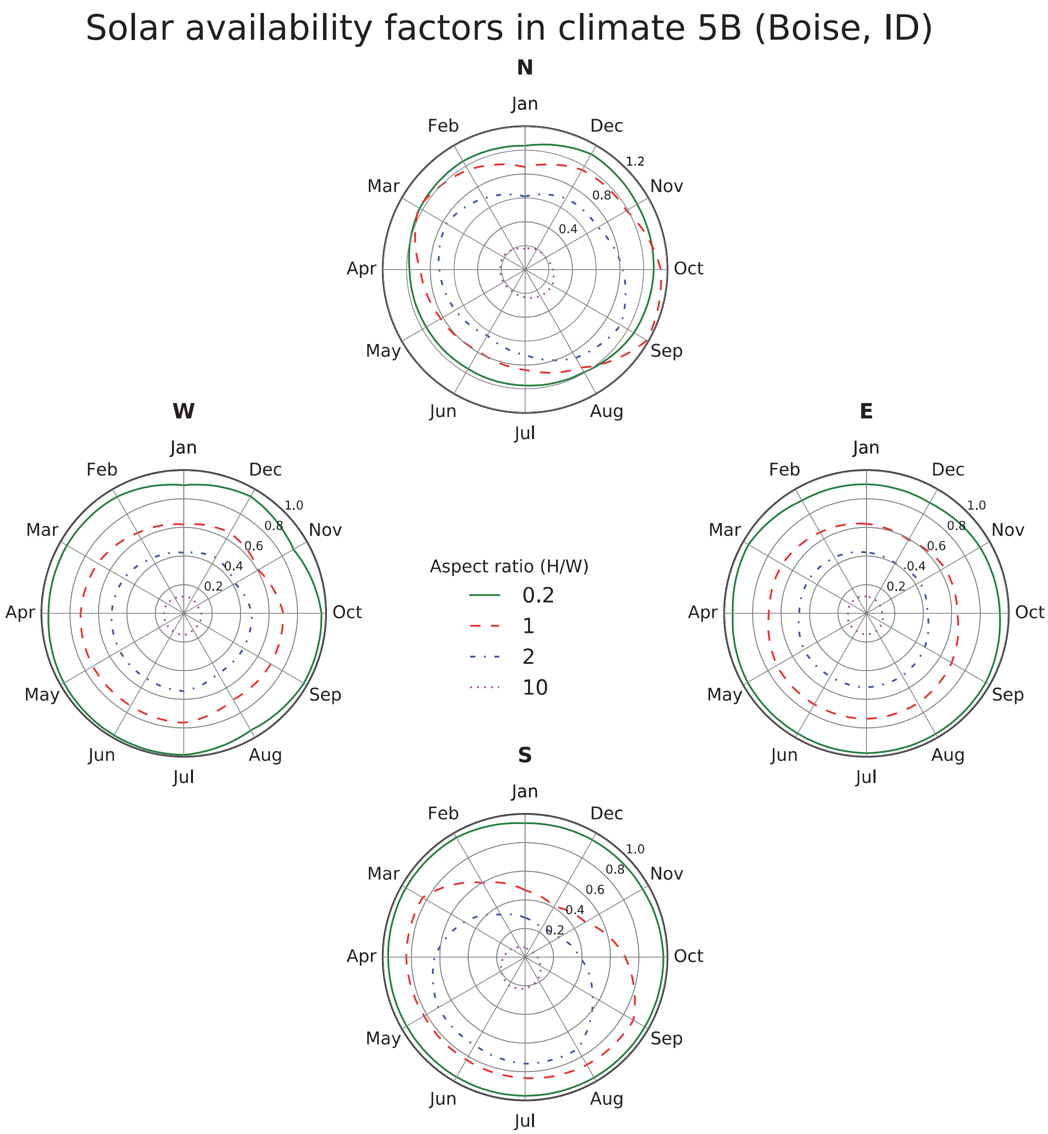
ESM Figure C-2 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(l)

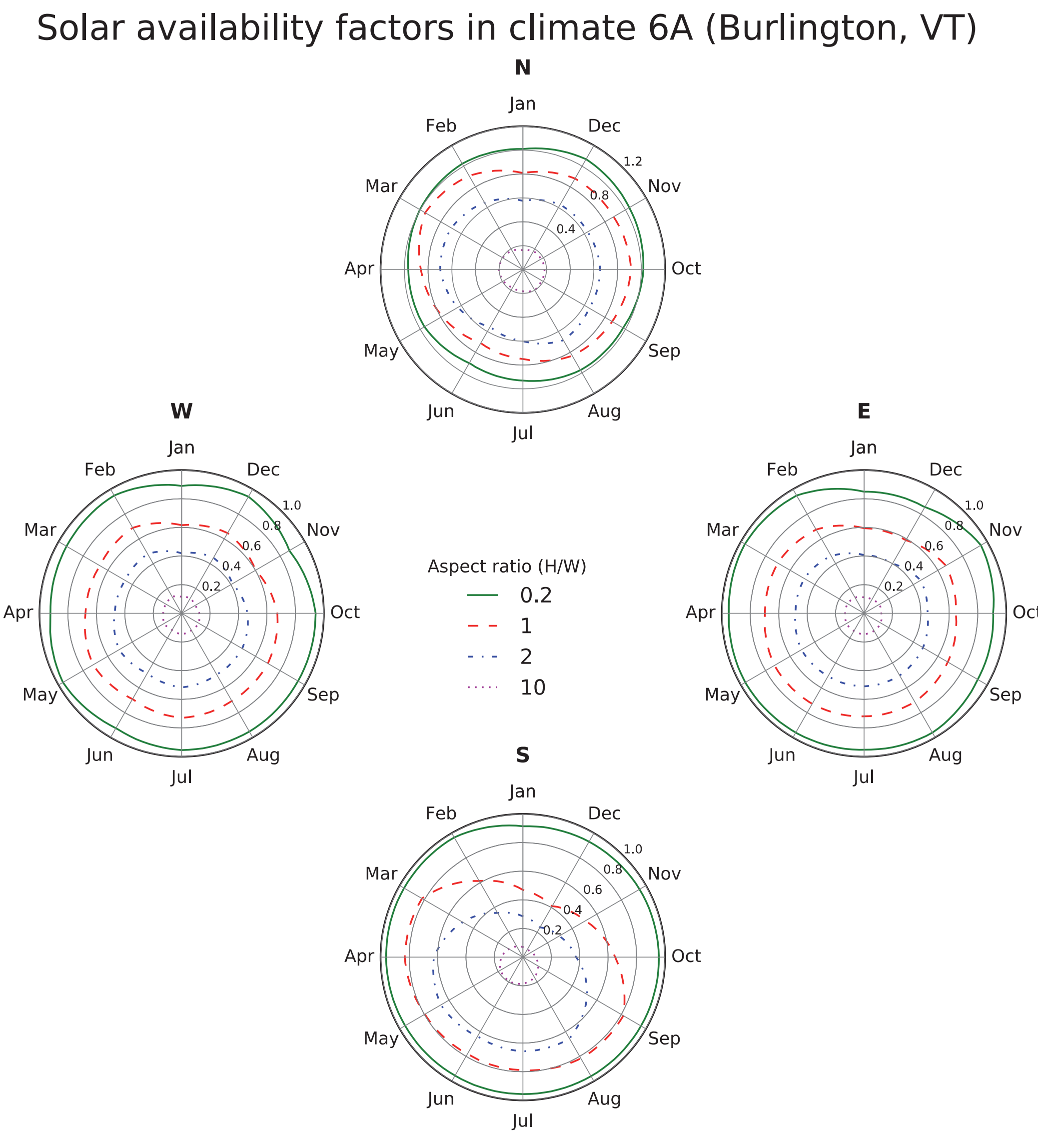
ESM Figure C-2 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(m)

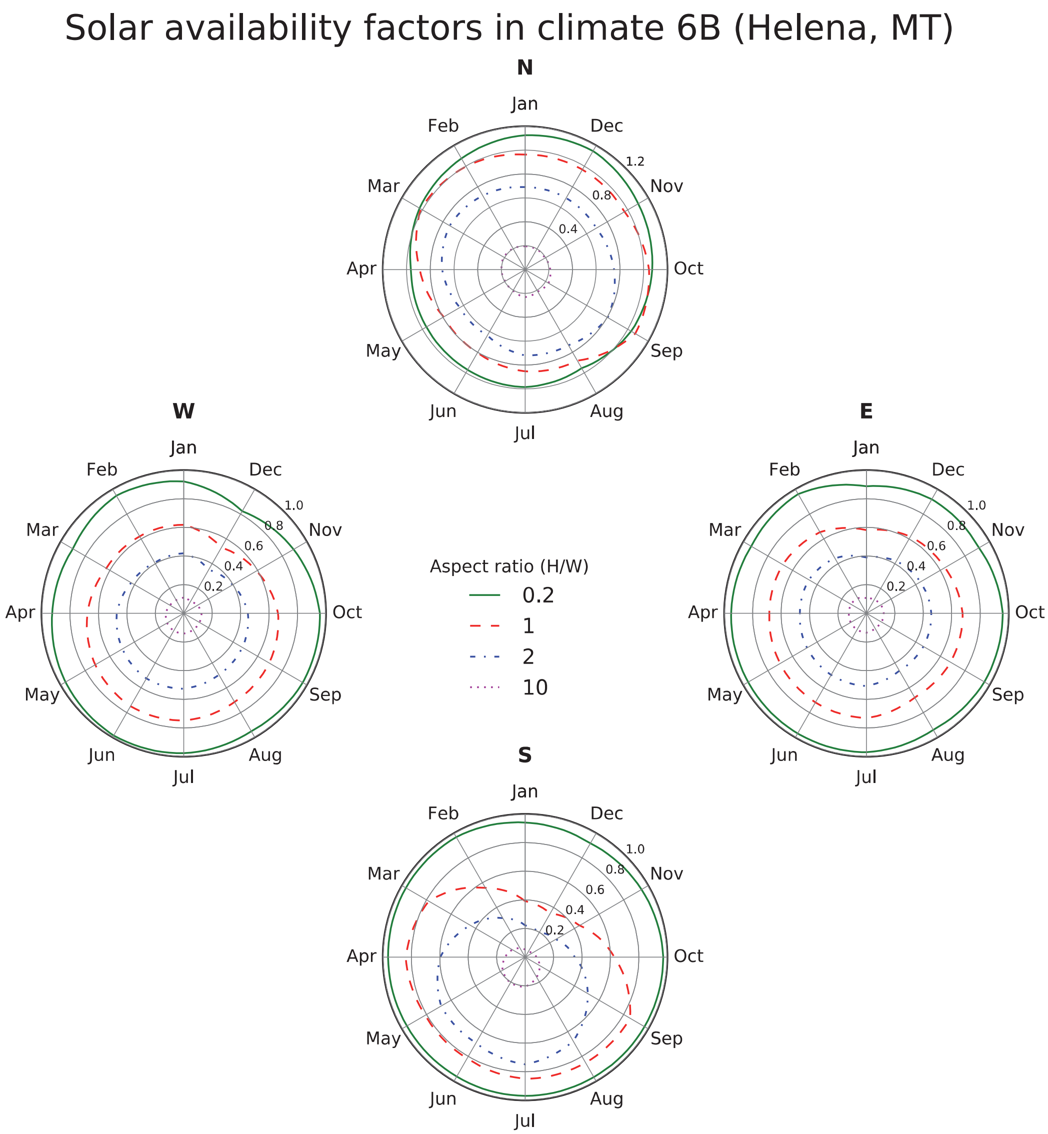
ESM Figure C-2 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(n)

ESM Figure C-2 (continued)

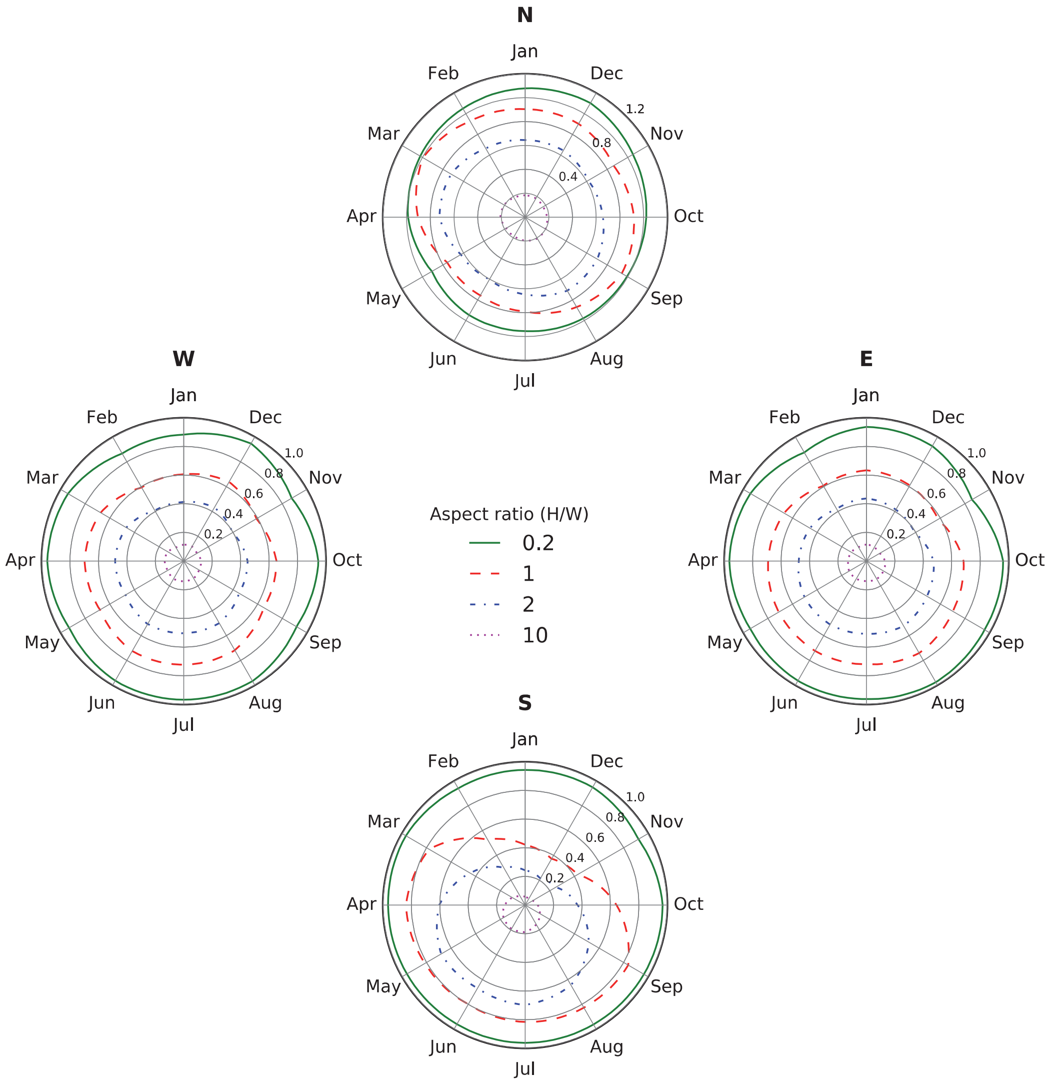


ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(o)

ESM Figure C-2 (continued)

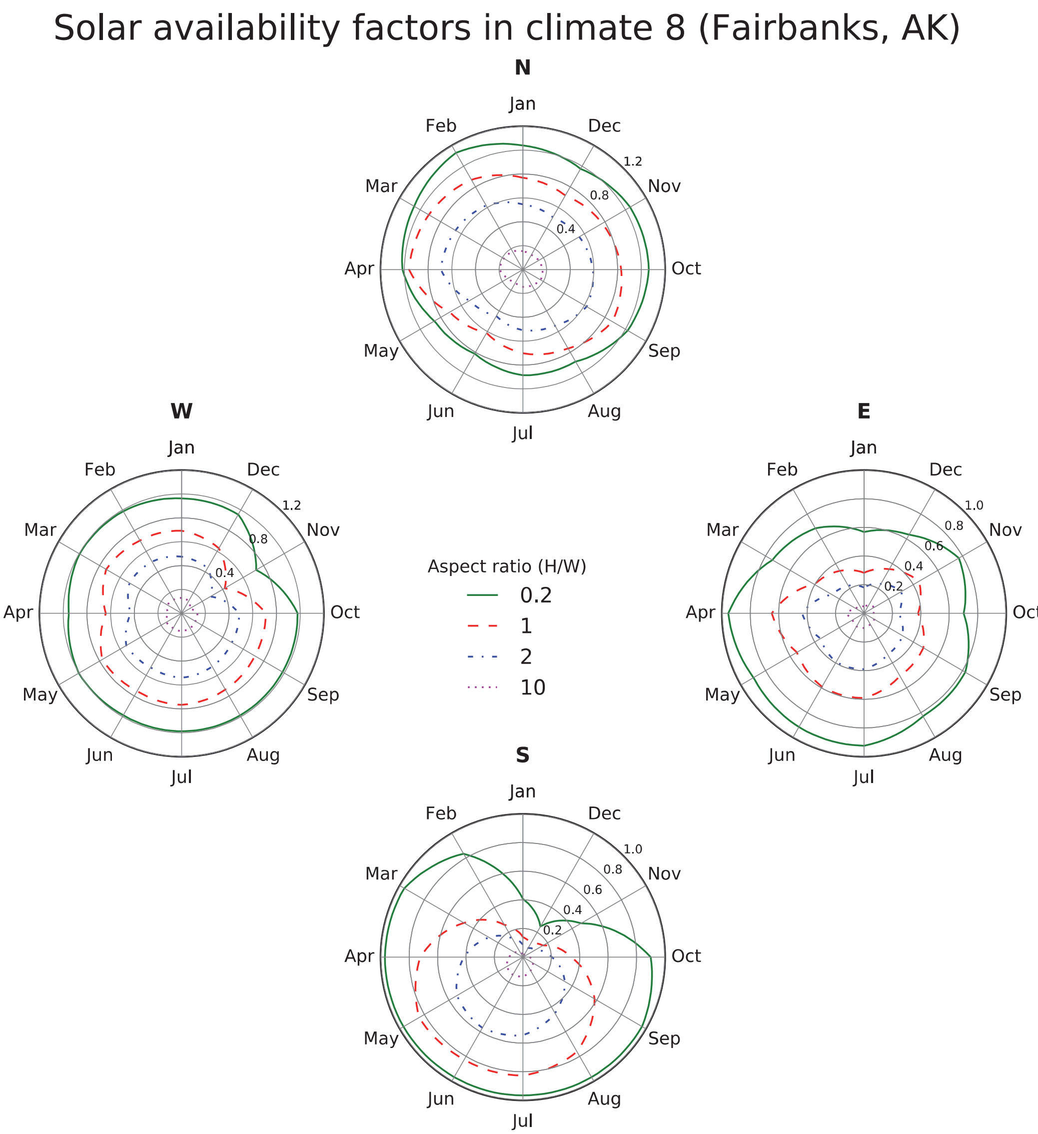
Solar availability factors in climate 7 (Duluth, MN)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(p)

ESM Figure C-2 (continued)

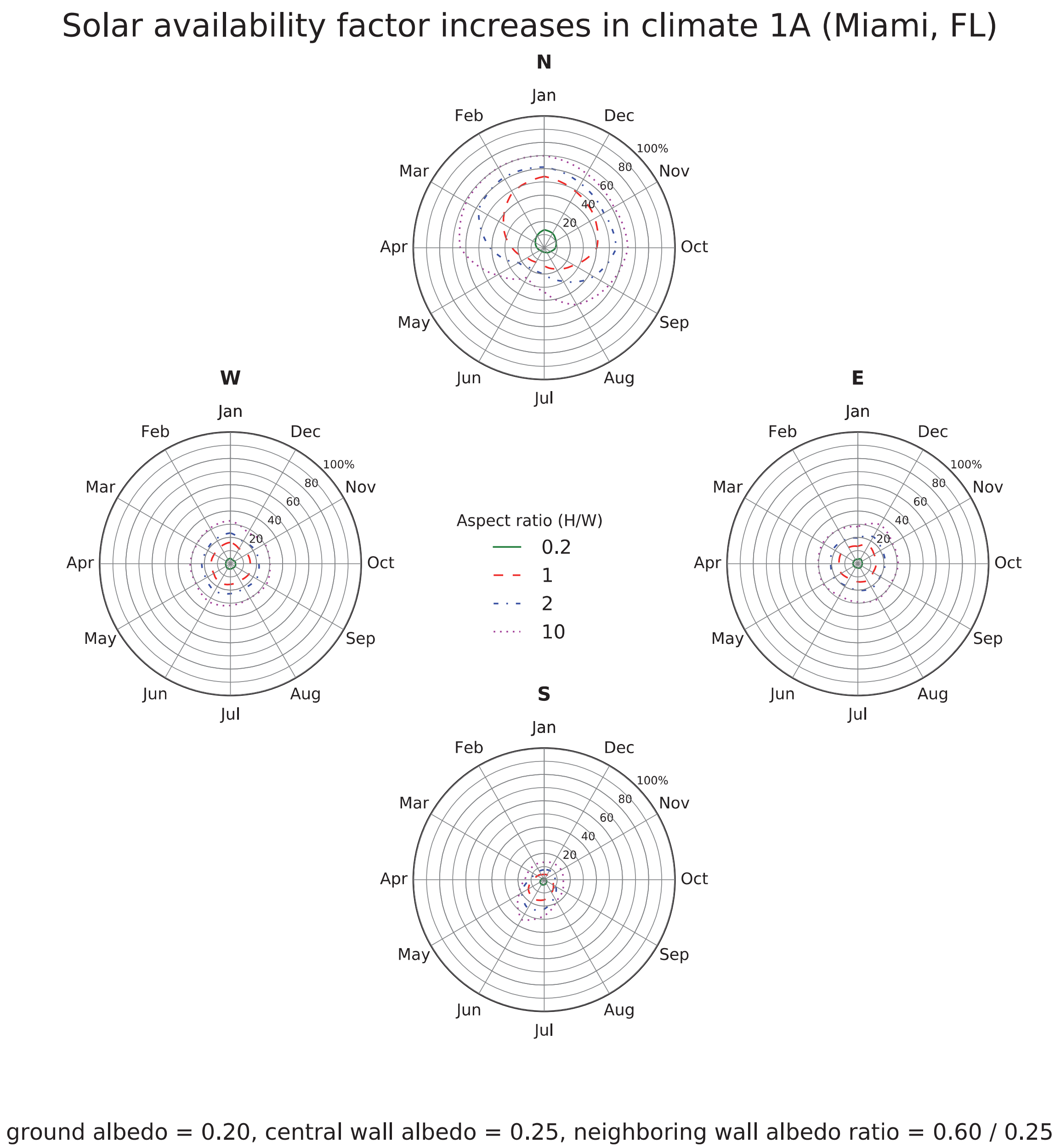


ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo = 0.60

(q)

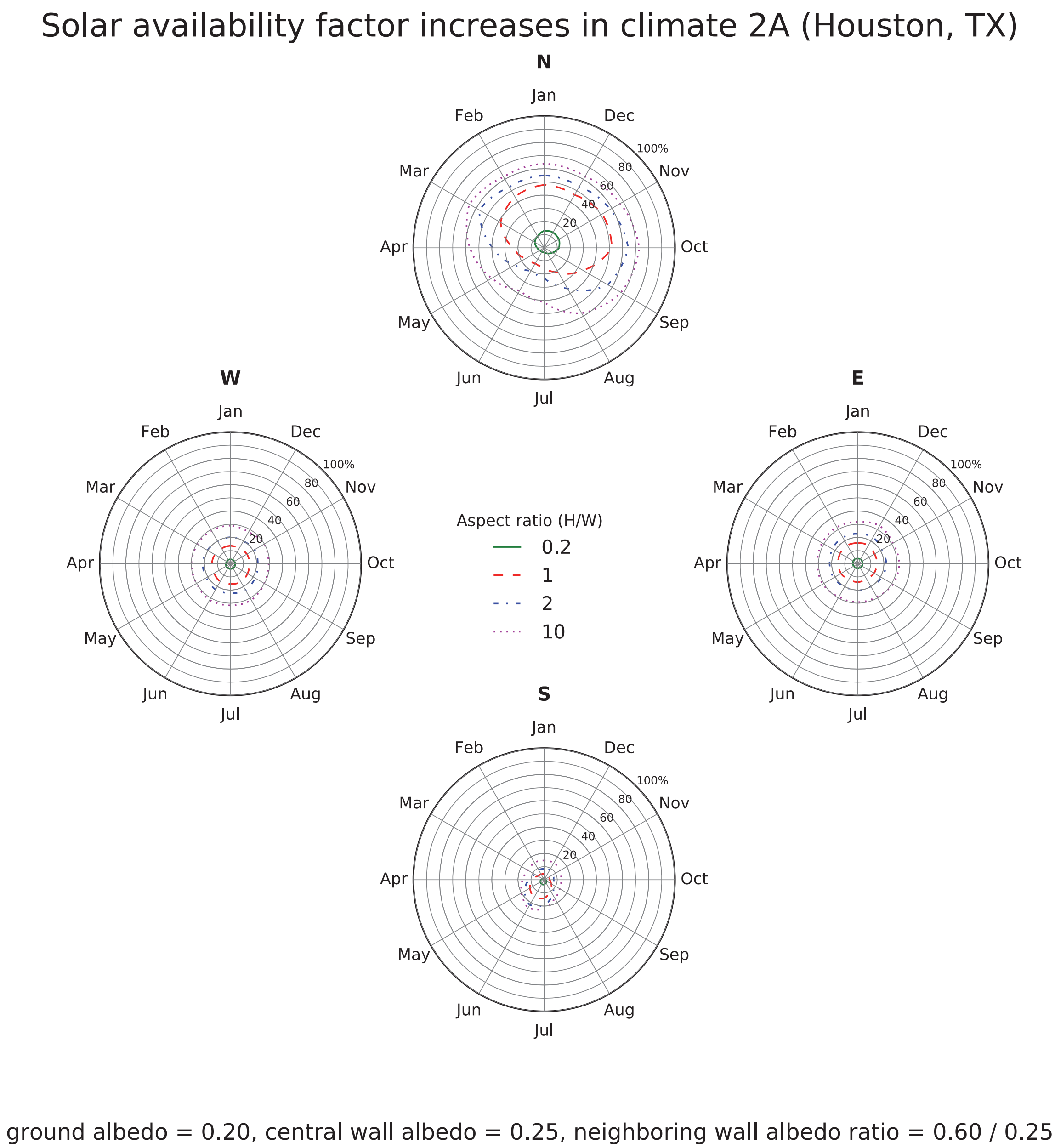
ESM Figure C-2 (continued)

ESM Appendix D: Monthly SAF increase plots by climate zone



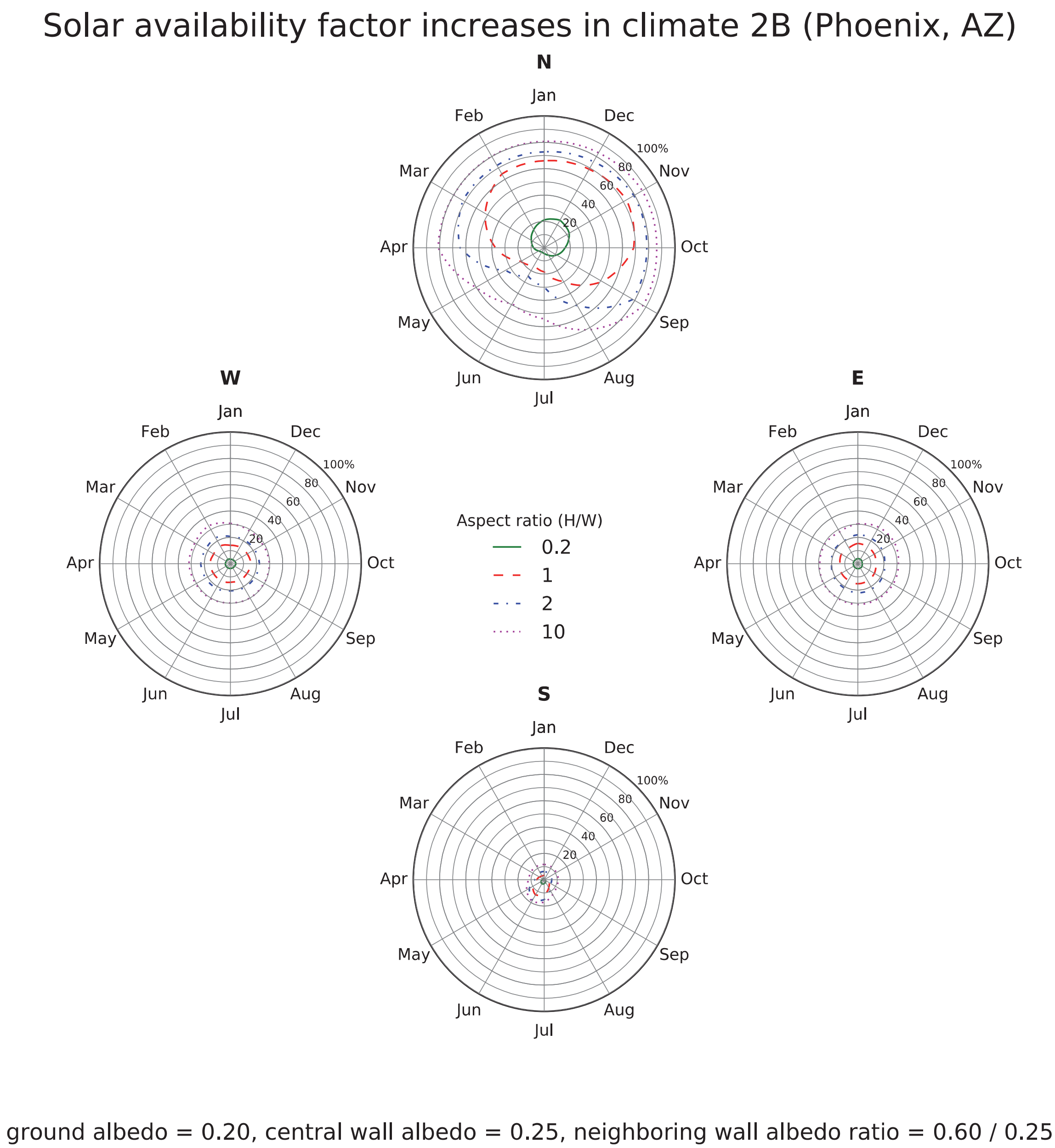
(a)

ESM Figure D-1. Percentage increases in monthly SAFs for a north (N), east (E), south (S), or west (W) conventional central wall (ρ=0.25) upon raising the albedo of its neighboring wall to 0.60 (cool) from 0.25 (conventional). Results shown for aspect ratios 0.2, 1, 2, and 10 in each of 17 climates (panels a through q).



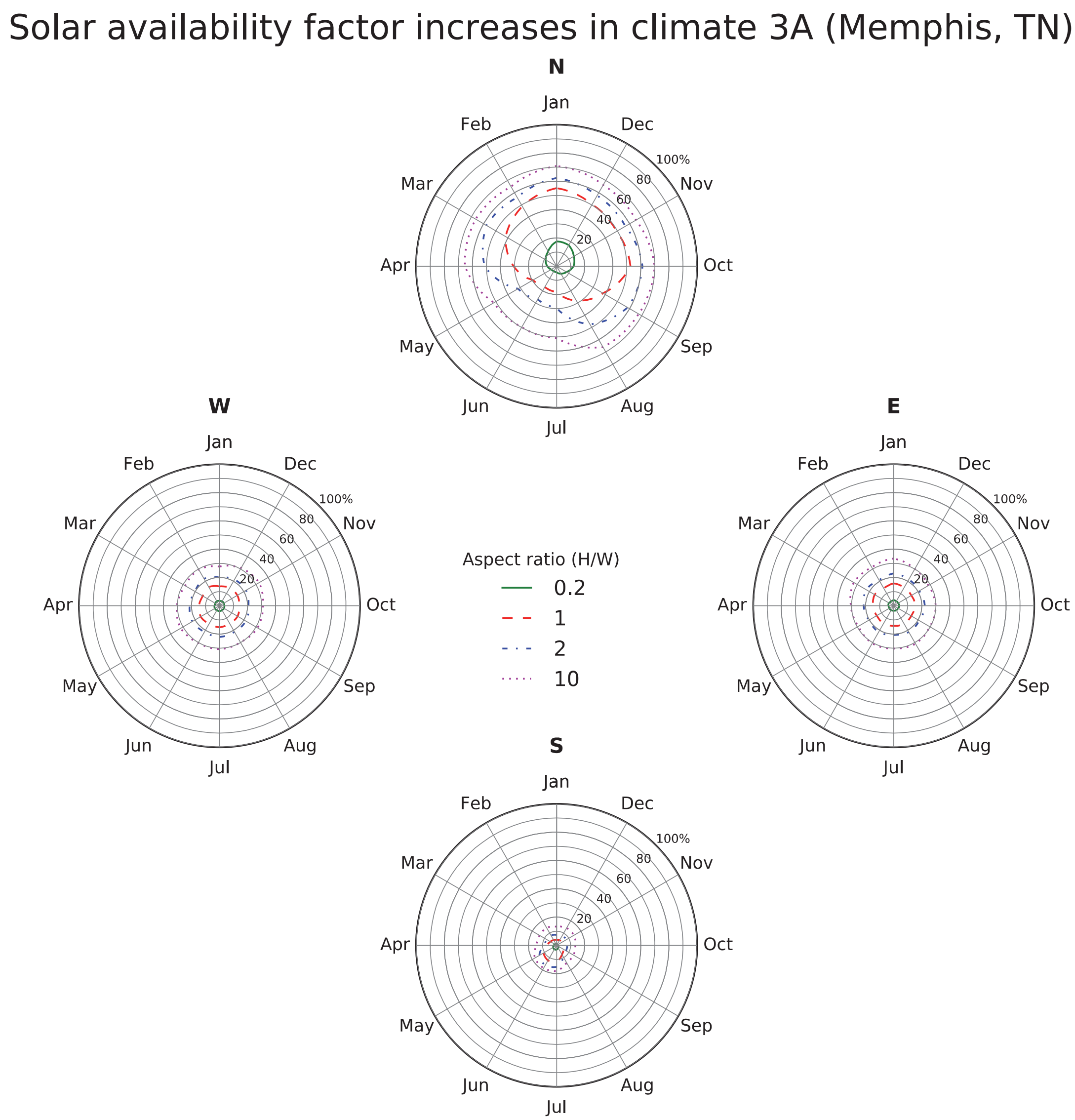
(b)

ESM Figure D-1 (continued)



(c)

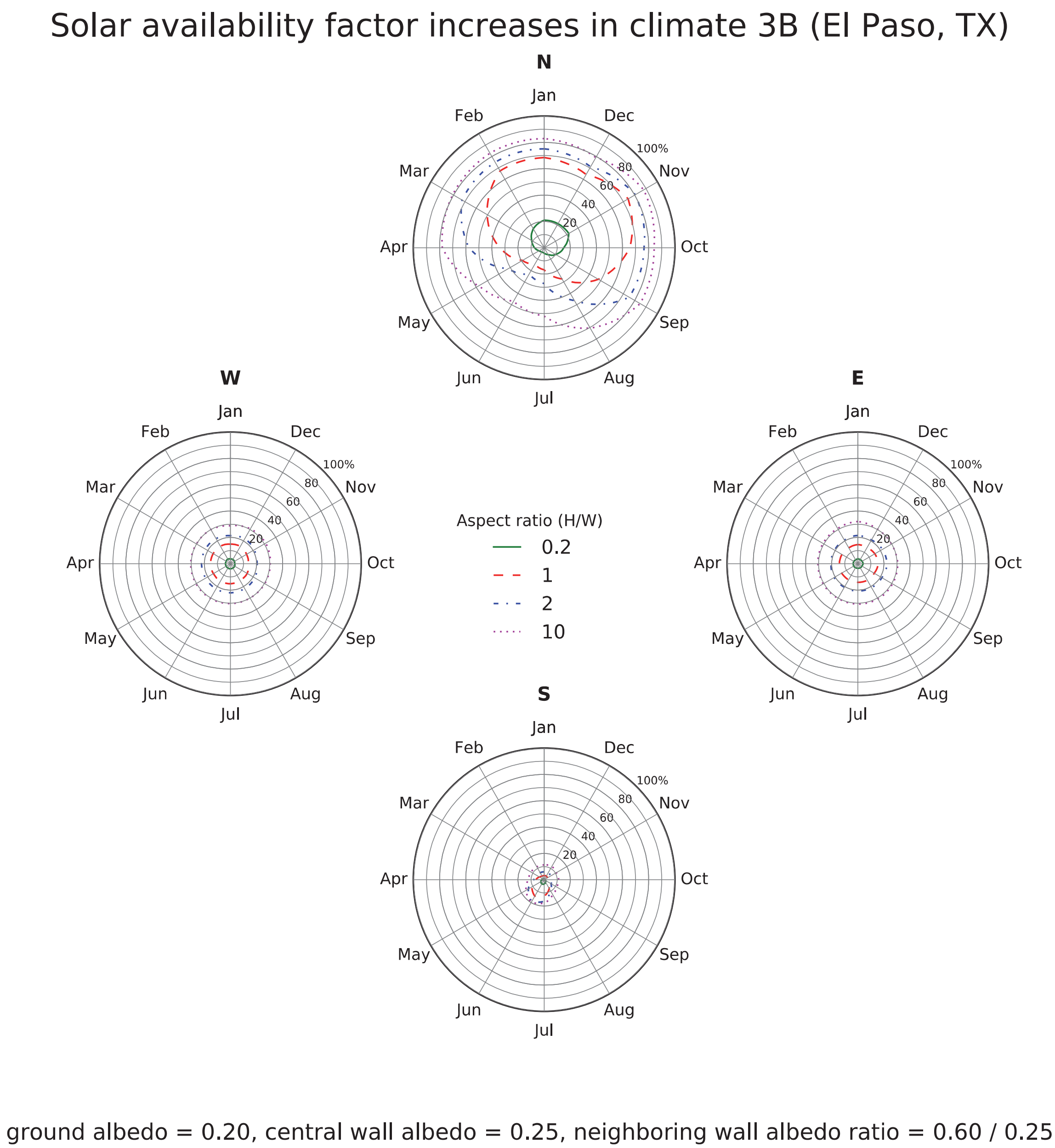
ESM Figure D-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

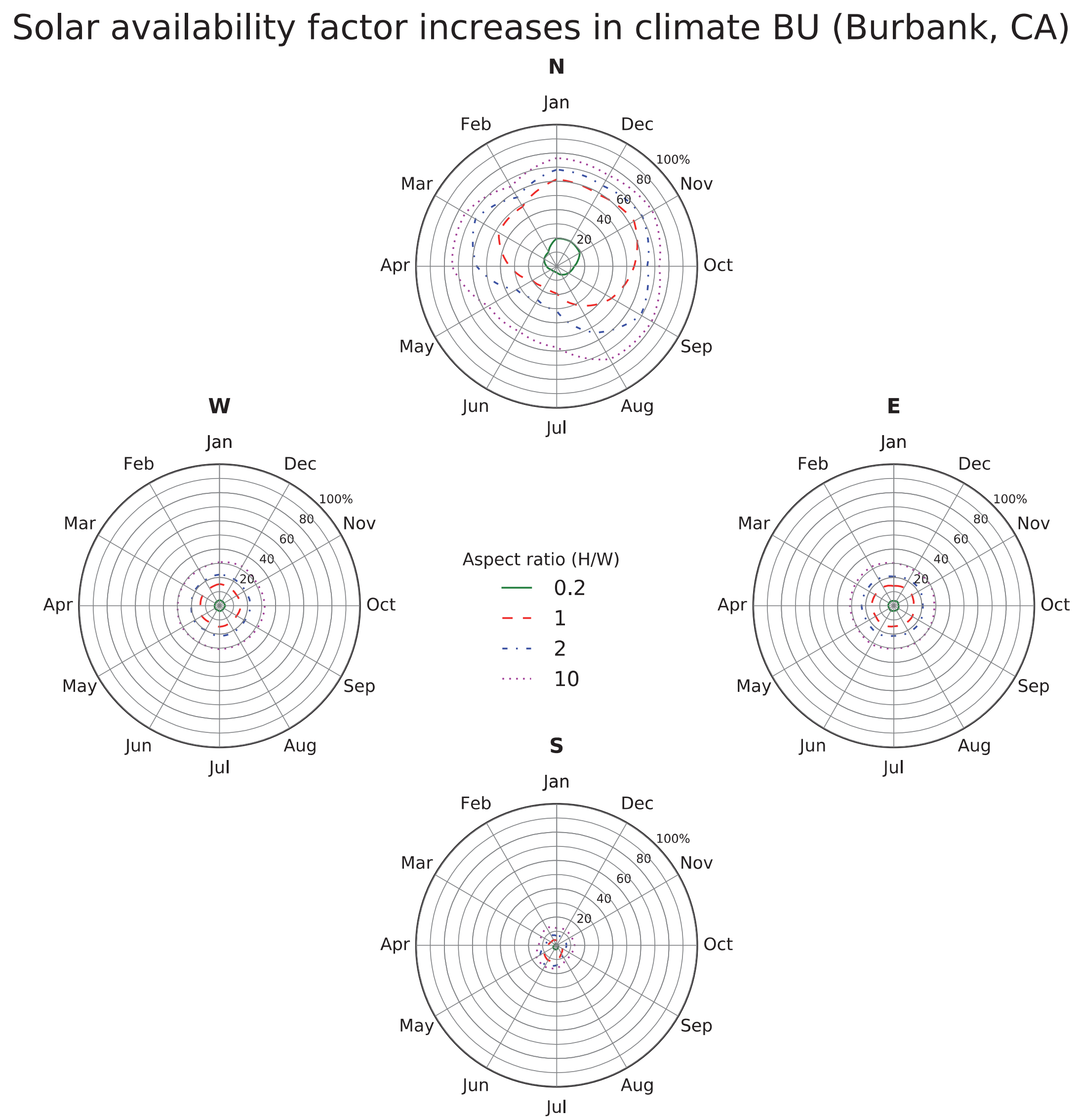
(d)

ESM Figure D-1 (continued)



(e)

ESM Figure D-1 (continued)

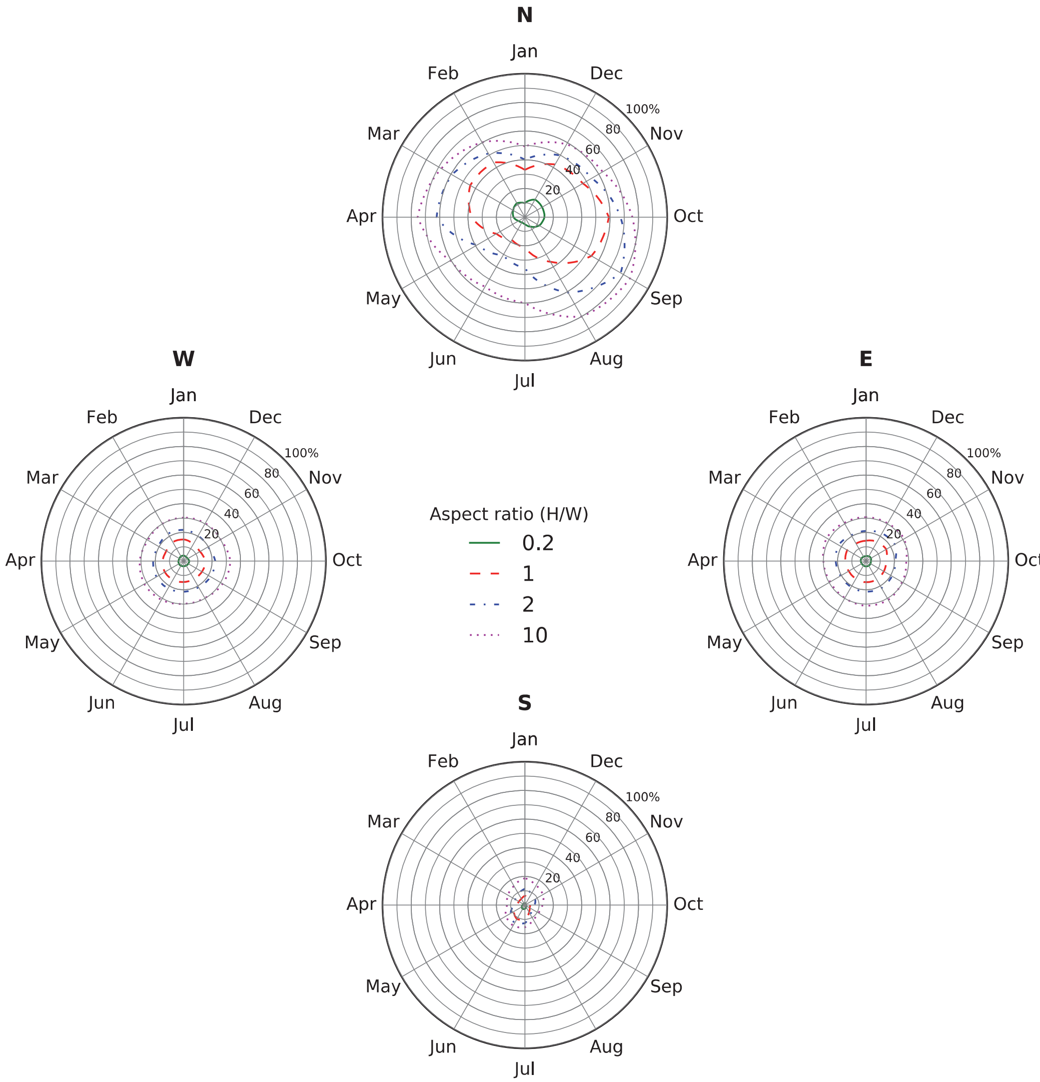


ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

(f)

ESM Figure D-1 (continued)

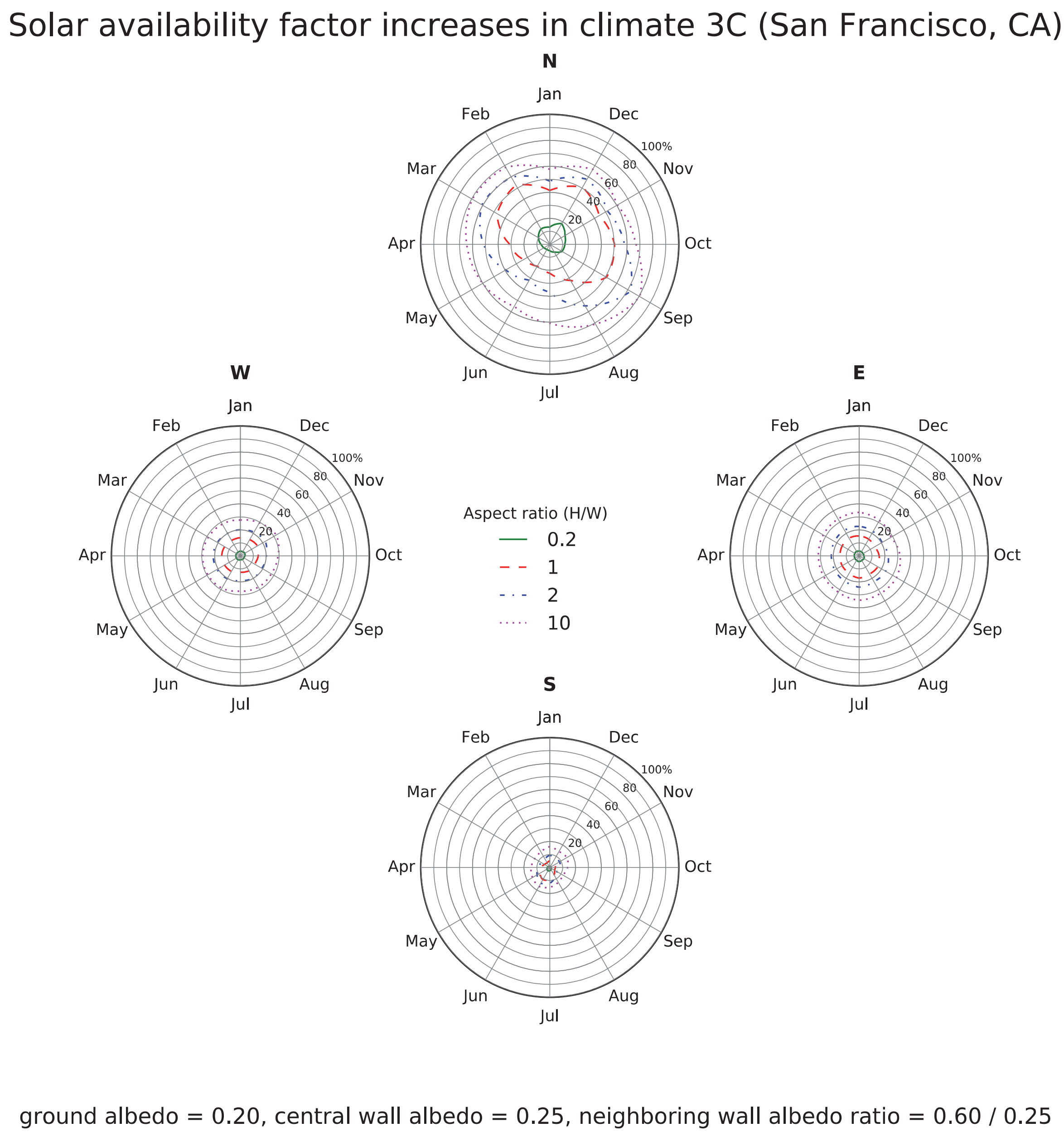
Solar availability factor increases in climate FR (Fresno, CA)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

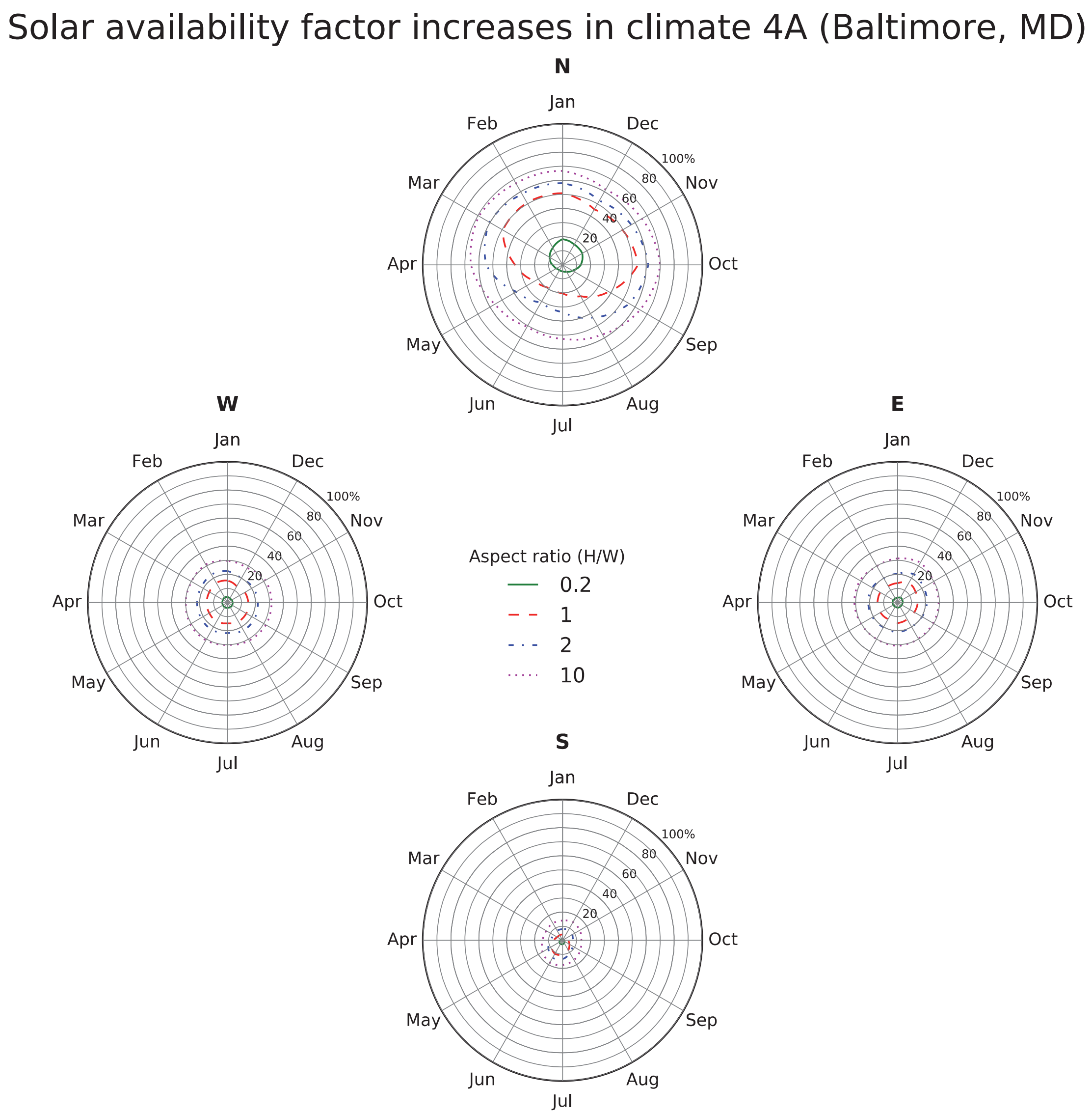
(g)

ESM Figure D-1 (continued)



(h)

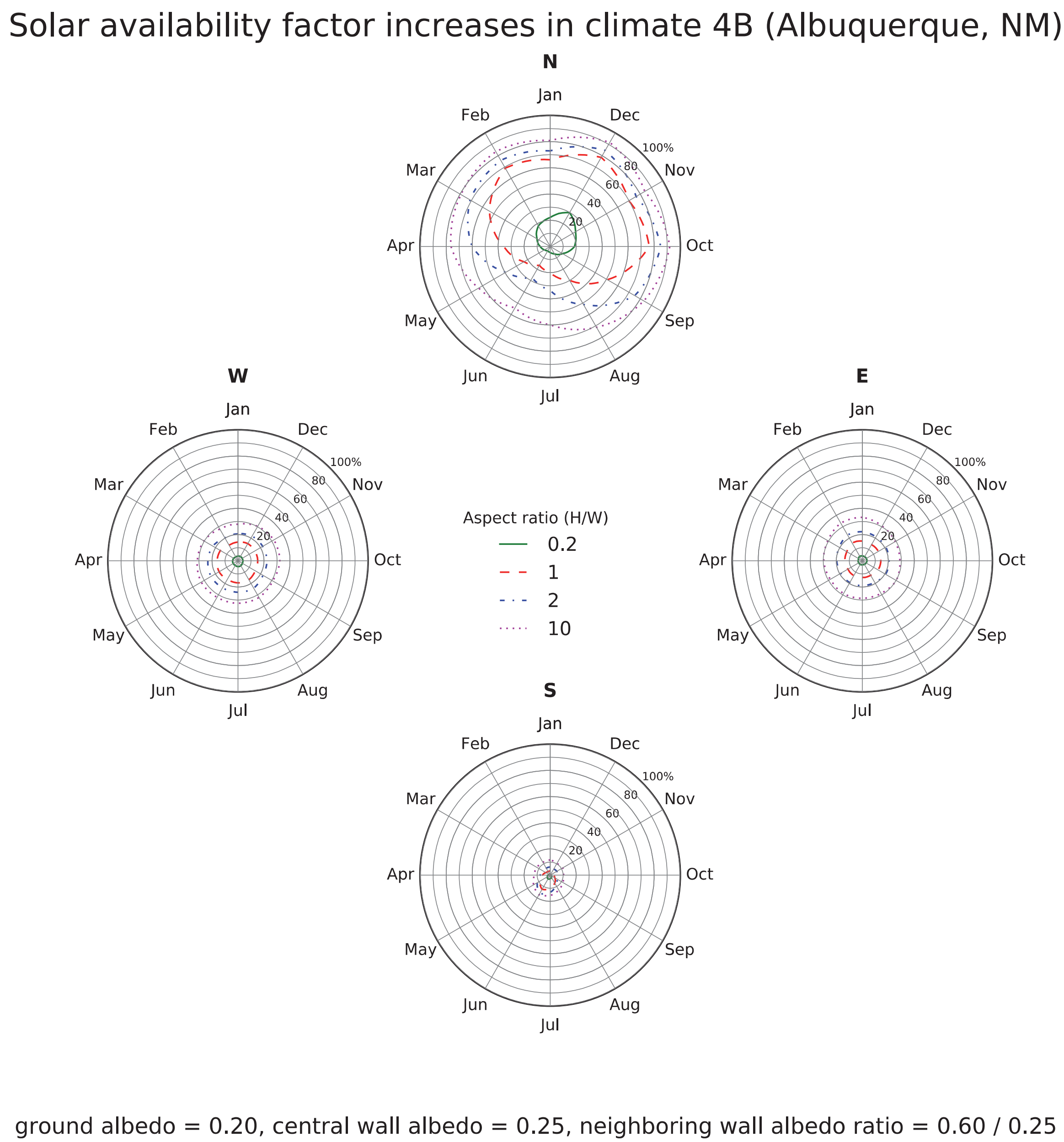
ESM Figure D-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

(i)

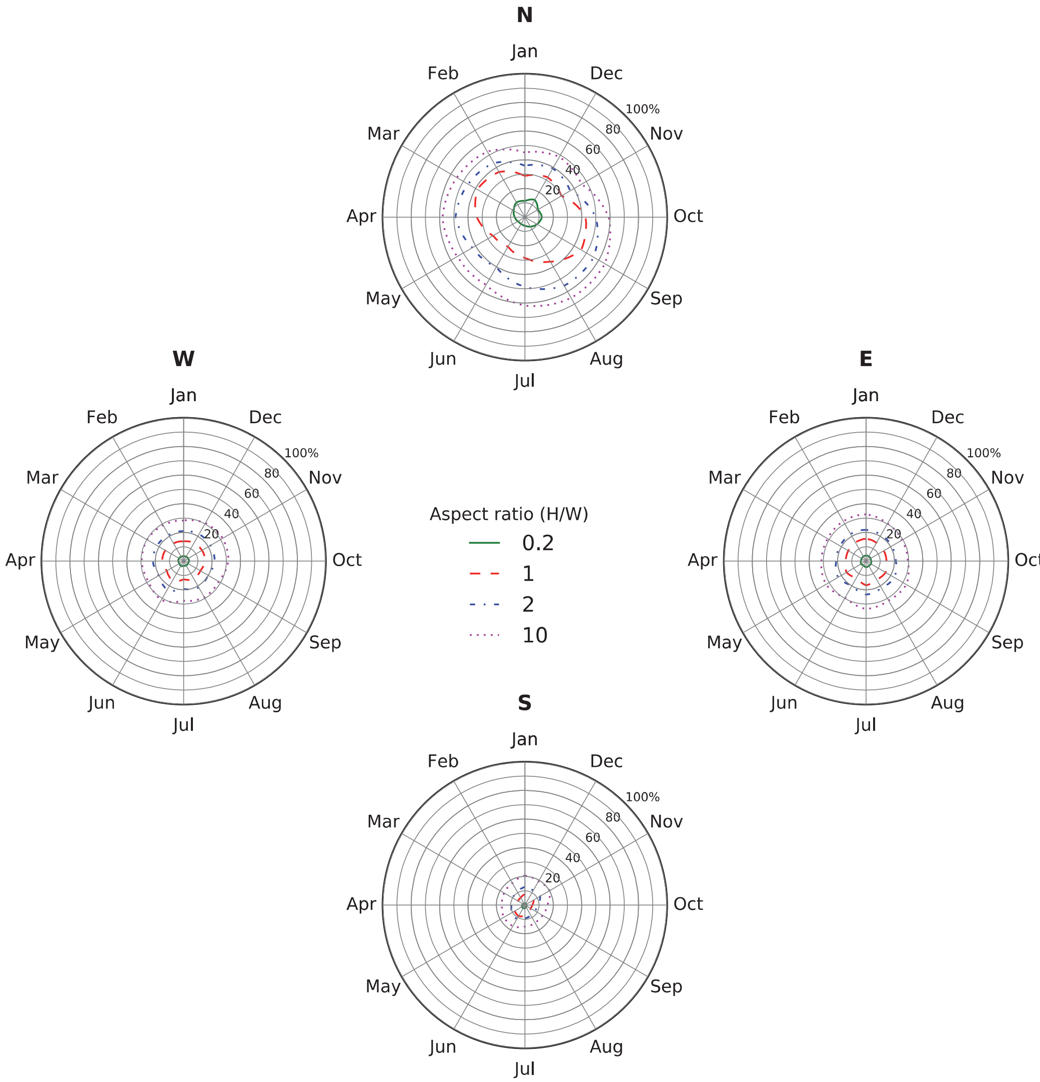
ESM Figure D-1 (continued)



(j)

ESM Figure D-1 (continued)

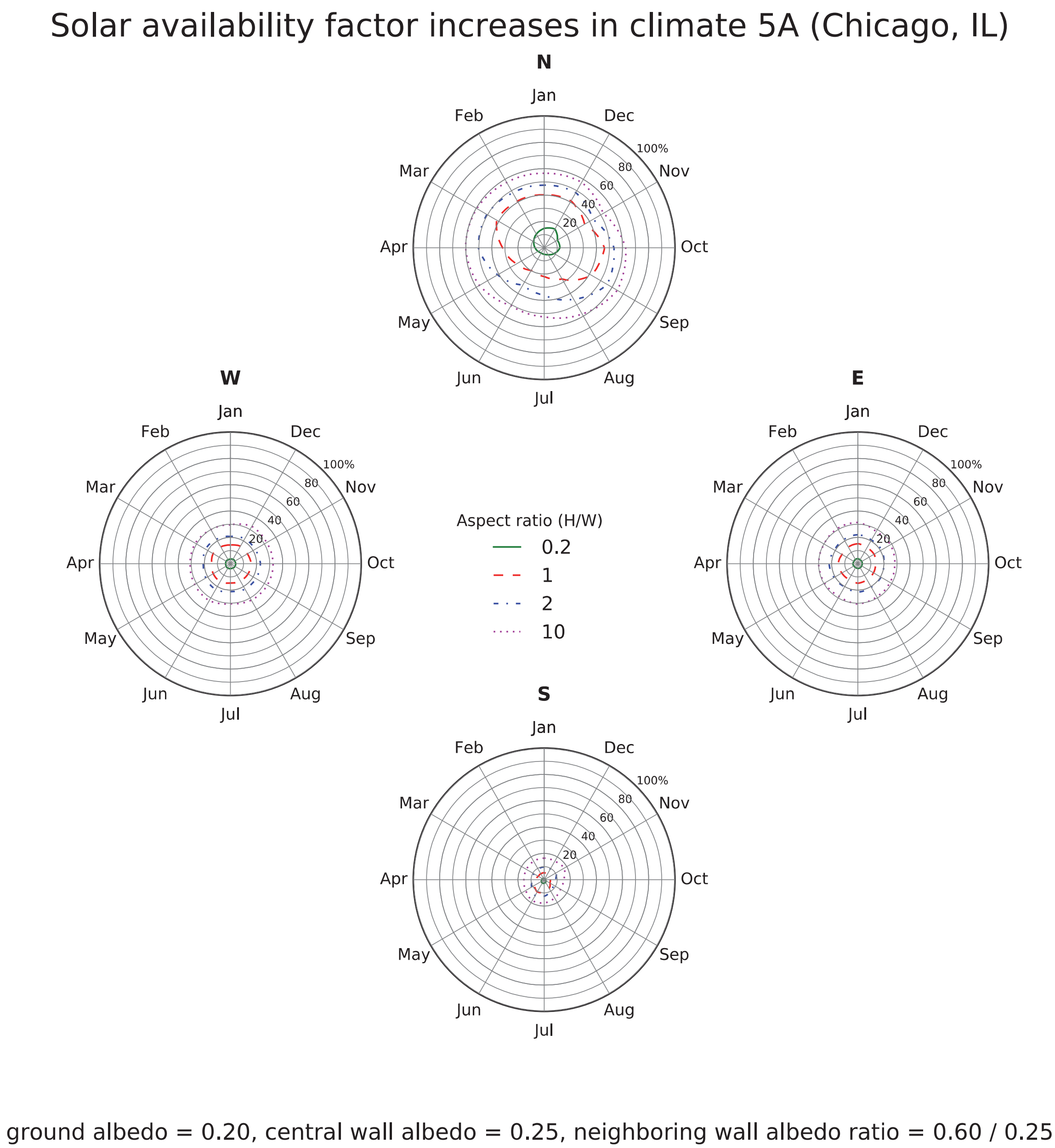
Solar availability factor increases in climate 4C (Seattle, WA)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

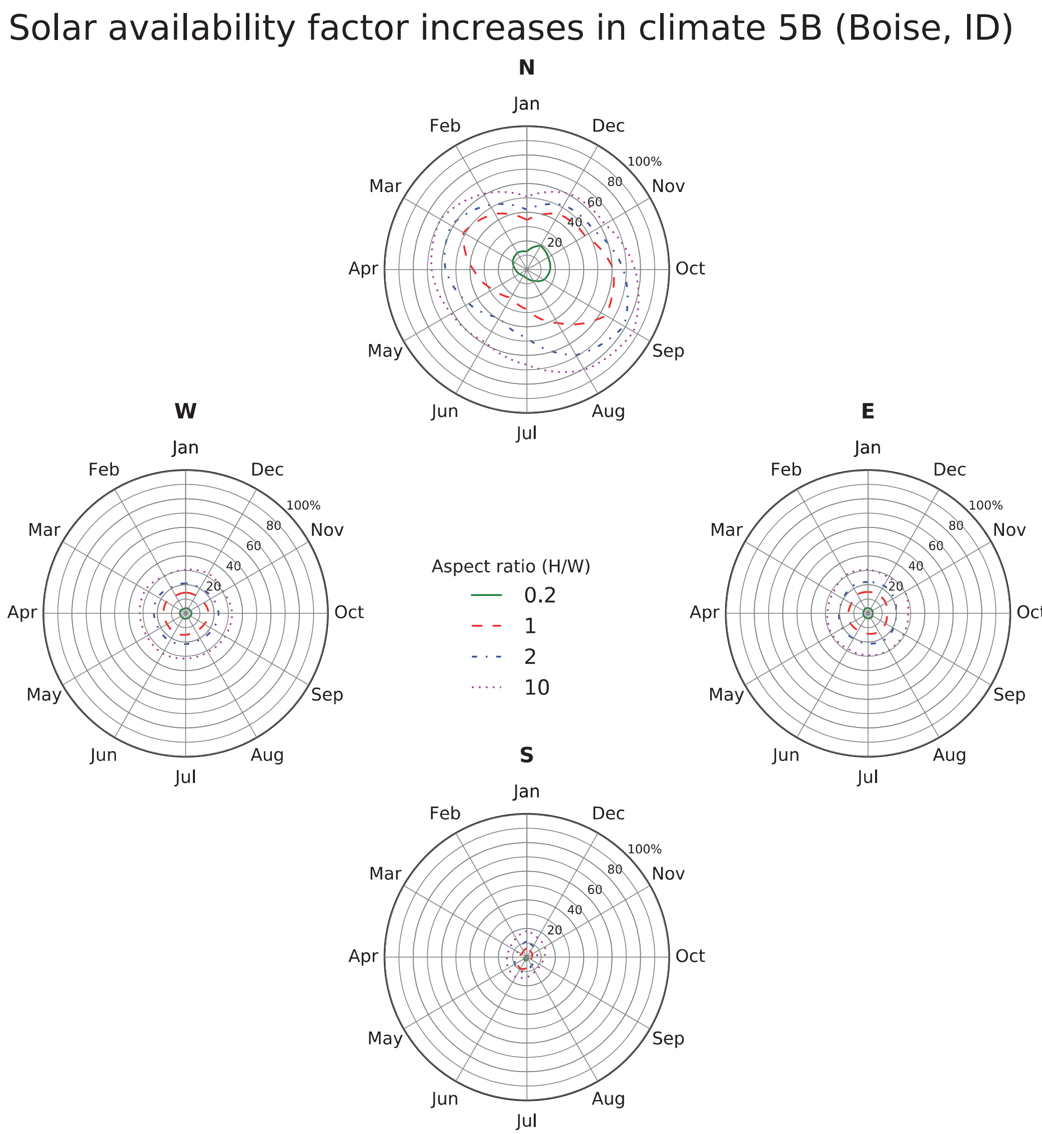
(k)

ESM Figure D-1 (continued)



(l)

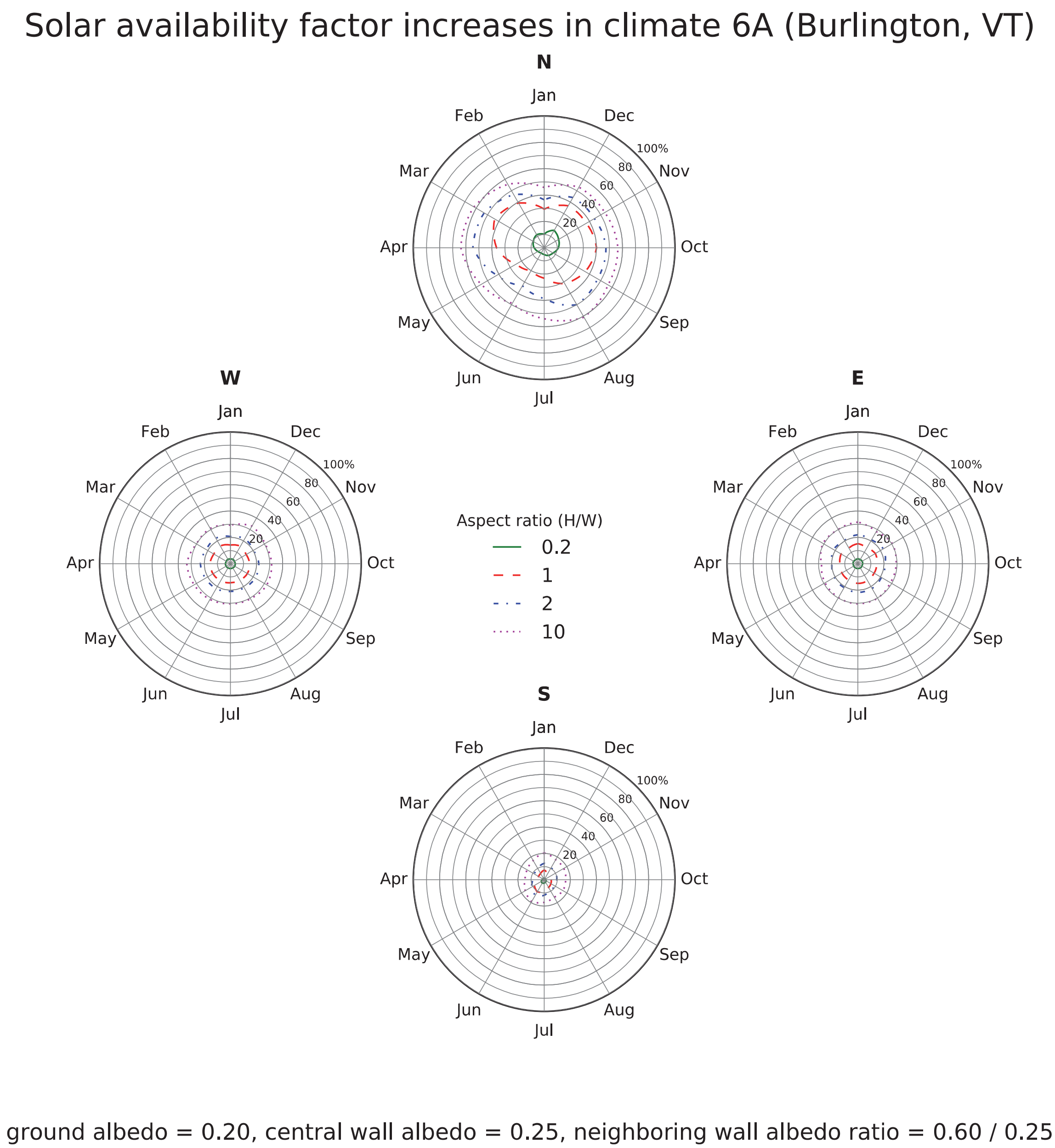
ESM Figure D-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

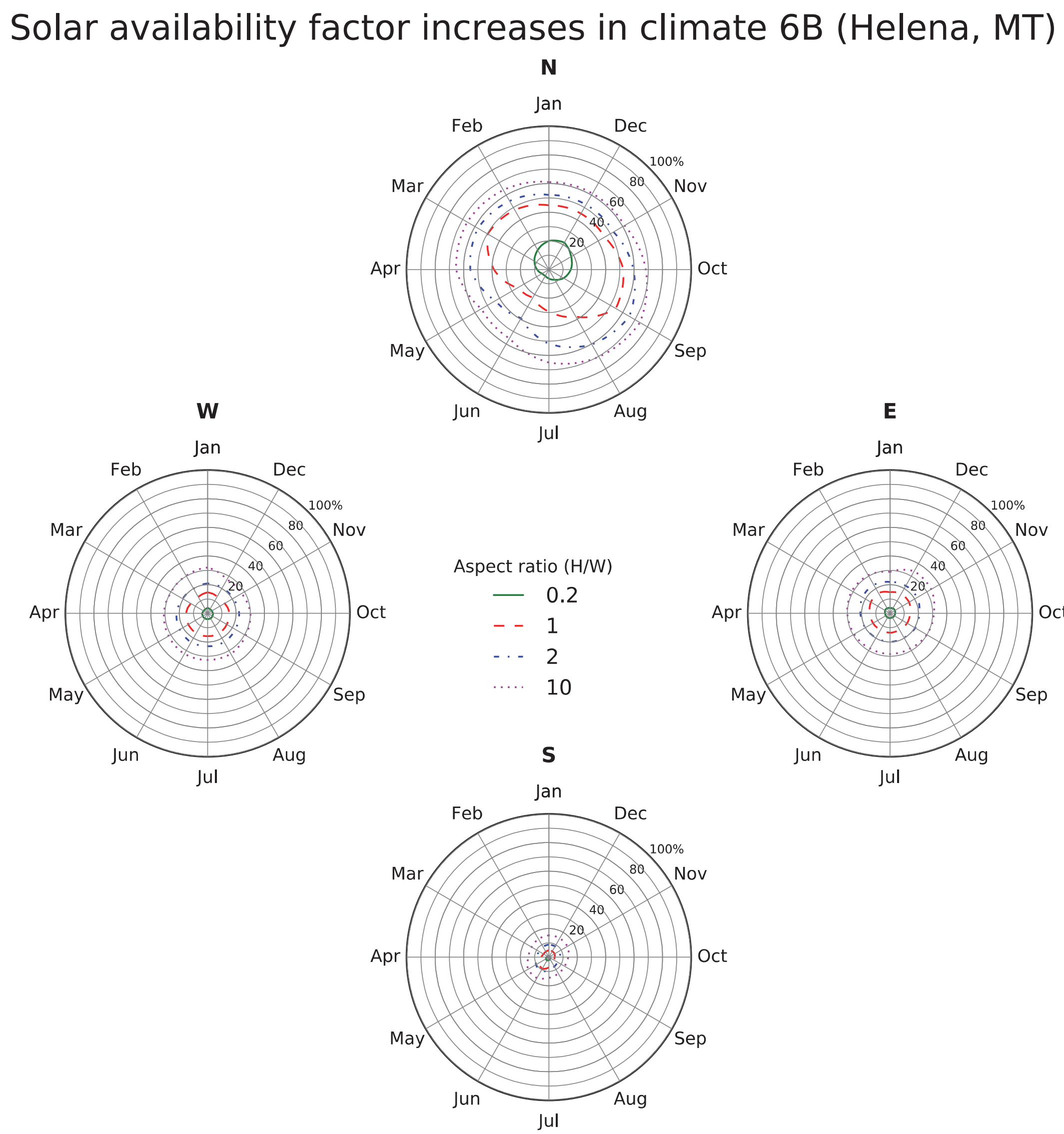
(m)

ESM Figure D-1 (continued)



(n)

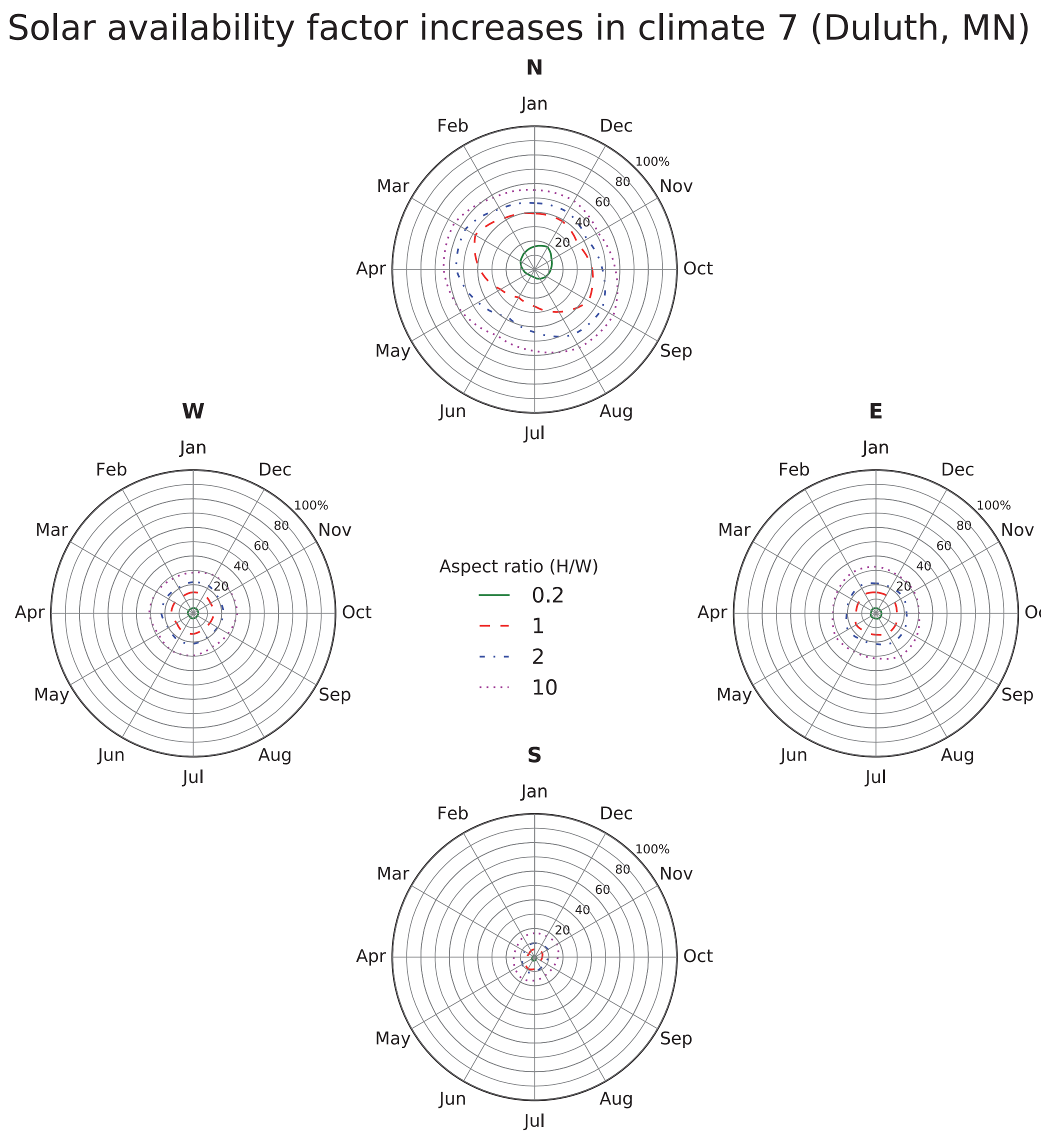
ESM Figure D-1 (continued)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

(o)

ESM Figure D-1 (continued)

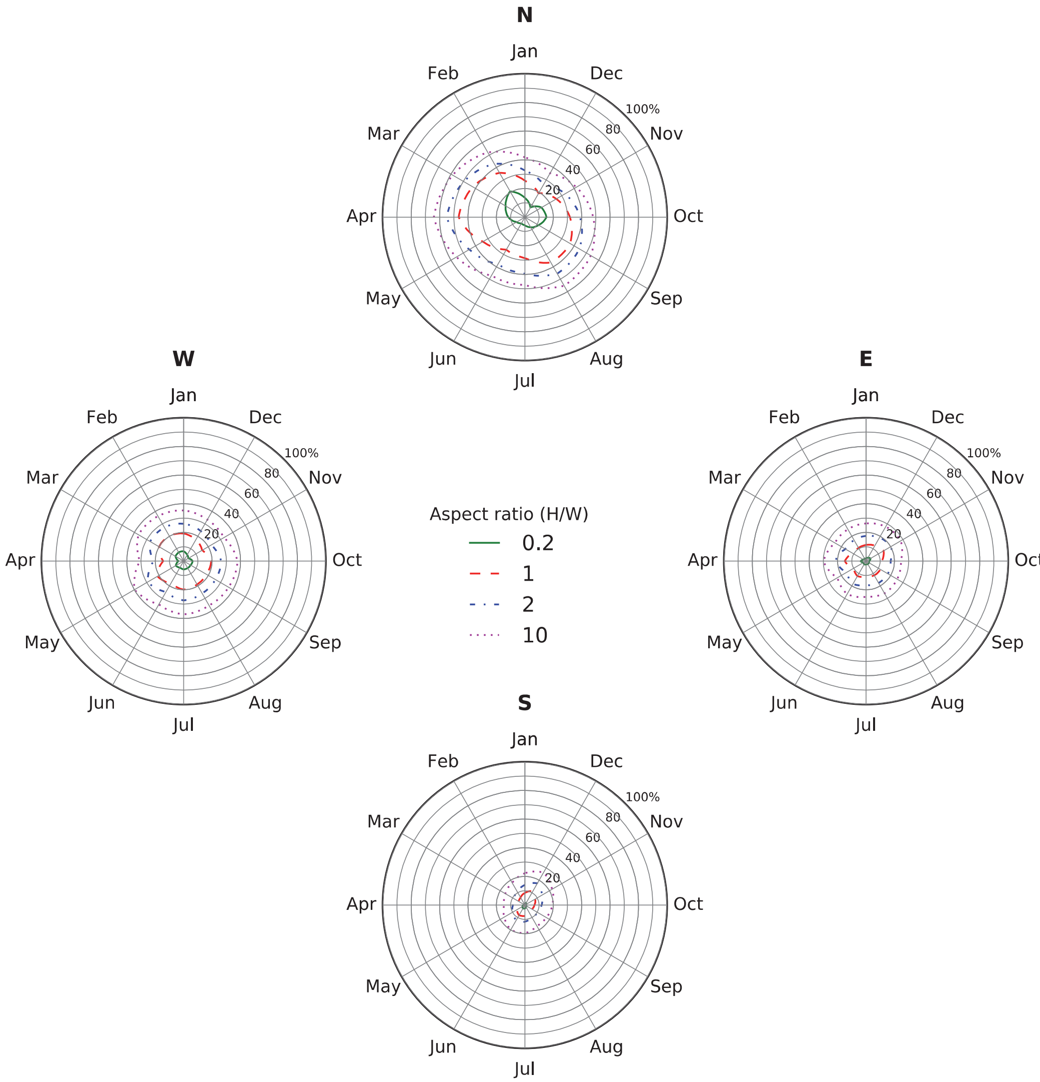


ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

(p)

ESM Figure D-1 (continued)

Solar availability factor increases in climate 8 (Fairbanks, AK)



ground albedo = 0.20, central wall albedo = 0.25, neighboring wall albedo ratio = 0.60 / 0.25

(q)

ESM Figure D-1 (continued)